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AN OPERATING AND SUPPORT COST MODEL FOR AVIONICS AUTOMATIC TEST--ETC(U)
SEP 79 J A GUERRA , A J LESKO , J G PEREIRA
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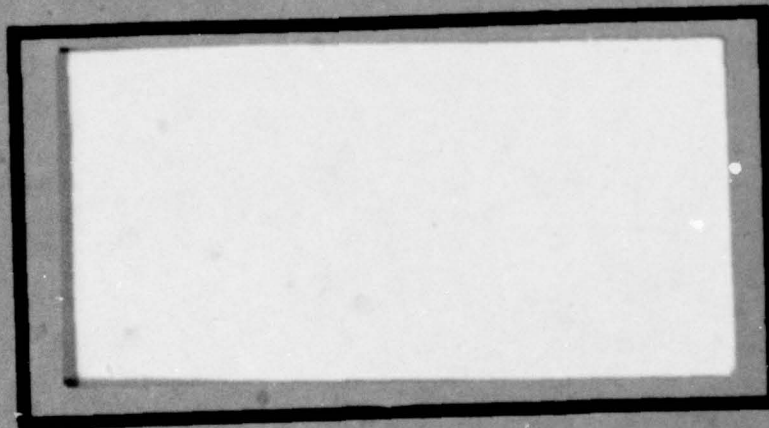


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6 AN OPERATING AND SUPPORT COST
MODEL FOR AVIONICS AUTOMATIC
TEST EQUIPMENT.

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One of the fastest growing elements of weapon system support equipment which relates directly to Operating and Support (O&S) costs is Automatic Test Equipment (ATE). The importance of ATE has expanded to such a degree that it requires additional management attention. The importance is exemplified by the \$600 million projected development and acquisition costs of ATE for the F-16. This amount of cost qualifies the F-16 ATE for major program status. This thesis documents the development of a model to estimate and measure O&S costs for avionics ATE. The model will be an important addition to the tools used in ATE Life Cycle Costing (LCC) techniques. It is envisioned primarily as an evaluation tool to be used in ATE source selection, but may also be useful in various design trade-off studies.

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AN OPERATING AND SUPPORT COST MODEL FOR
AVIONICS AUTOMATIC TEST EQUIPMENT

A Thesis

Presented to the Faculty of the School of Systems and Logistics
of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the
Degree of Master of Science in Logistics Management

By

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fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN LOGISTICS MANAGEMENT

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TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	iii
LIST OF TABLES	viii
LIST OF FIGURES	ix
 Chapter	
I. INTRODUCTION	1
Statement of the Problem	2
Background and Justification	3
Research Objective	5
Research Questions	5
II. LITERATURE REVIEW	7
Models	7
Mathematical Models	9
Logistics Models	10
Life Cycle Cost Models	12
Logistics Support Cost Commitments (LSCC) Technique	16
Framework for an LSC Model	17
Target Logistics Support Cost	18
Implementation Considerations	19
Logistics Support Cost Model for Automatic Test Equipment	24
Reliability and Maintainability	24

Chapter	Page
Assumptions and Limitations for Model Development	25
Factors of the Logistics Support Cost Model	26
Cost of TRU Spares	27
On-Equipment Maintenance	27
Off-Equipment Maintenance	27
Inventory Management Costs	28
Cost of Support Equipment	28
Cost of Personnel Training	28
Cost of Management and Technical Data . .	29
Calibration Requirements	29
Summary	29
III. METHODOLOGY	31
Data Base and Data Validity	33
Existing Model Variables	35
Variables Used in Actual Cost Data	36
Selection of Variables	37
Relationships of Variables	38
Sensitivity Analysis	39
IV. MODEL DEVELOPMENT	41
Steps in Model Development	42
Identification of Variables	43
Relationship of Variables by Category . . .	45
Cost of TRU Spares (C_1)	46

Chapter	Page
On-Equipment Maintenance Costs (C_2) . . .	52
Off-Equipment Maintenance Costs (C_3) . . .	54
Inventory Management (C_4)	58
Cost of Support Equipment (C_5)	60
Cost of Personnel Training (C_6)	66
Cost of Management and Technical Data (C_7)	70
Calibration Requirements Cost (C_8)	75
Summary	87
V. ANALYSIS OF THE MODEL	88
Computer Model	88
Output from the Model	89
Sensitivity Analysis	90
Mean Time Between Failure (MTBF)	90
Repair in Place (RIP)	94
Preparation and Access (PAMH), Corrective Maintenance (IMH), Fault Isolation and TRU Removal Manhours (RMH)	96
TRU Condemnation Rate (DCOND)	96
Base Level Spares Availability Objective (TARGAVAL)	99
Summary	101
VI. CONCLUSIONS AND RECOMMENDATIONS	103
Potential Model Uses	103
Model Limitations	104

	Page
Other Considerations in Model Use	105
Availability of Data	106
User Understanding and Acceptance of the Model	107
Model Assumptions	108
Recommendations for Further Study	108
Model Validation	109
Development of Equation C ₉ for Software	110
Test of Assumption Regarding Availability of ATE	110
APPENDICES	112
A. BASIC LSC MODEL FRAMEWORK	113
B. VARIABLE MATRIX	117
C. VARIABLE DEFINITIONS	125
D. COMPUTER PROGRAM	133
E. SAMPLE DATA BASE	146
F. SAMPLE OUTPUT	153
SELECTED BIBLIOGRAPHY	161
A. REFERENCES CITED	162
B. RELATED SOURCES	164

LIST OF TABLES

Table	Page
1. Cost of TRU Spares (C_1)	47
2. On-Equipment Maintenance (C_2)	53
3. Off-Equipment Maintenance (C_3)	55
4. Inventory Management Cost (C_4)	59
5. Cost of Support Equipment (C_5)	61
6. Cost of Personnel Training (C_6)	67
7. Cost of Management and Technical Data (C_7)	71
8. Calibration Requirements (C_8)	76

LIST OF FIGURES

Figure	Page
1. Steps Included in Methodology	32
2. TLSC vs. MTBF	92
3. TLSC vs. MTBF and UC	93
4. TLSC vs. RIP	95
5. TLSC vs. PAMH IMH RMH	97
6. TLSC vs. DCOND	98
7. TLSC vs. TARGAVAL	100

CHAPTER I

INTRODUCTION

In today's complex defense environment, great emphasis is placed on the development and acquisition of weapon systems that provide the most for each dollar. When speaking of weapon systems there is often a tendency to overlook the importance of "all the equipment required on the ground to make a weapon system . . . operational in its intended environment [1:A2-1]." This equipment, known as Support Equipment (SE), runs the gamut from low cost hand tools to multimillion dollar computer operated automatic test stations (23:1).

"The development and acquisition of Support Equipment are integral parts of a defense system acquisition program [23:1]." The cost of SE for Air Force weapon systems presently ranges from 5 percent to 15 percent of the total acquisition costs of the system. The importance of SE has grown so rapidly over recent years that the aggregate cost of all SE in the inventory in 1975 approached \$4.5 billion and has increased each year since. SE has a great influence on total Operating and Support (O&S) costs of the Air Force defense system (23:1). Due to inflation and technological advancement, the O&S costs of maintaining

current Air Force systems has grown to nearly 60 percent of potential expenditures (26).

One of the fastest growing elements of SE which relates directly to O&S costs is Automatic Test Equipment (ATE). The importance of ATE has expanded to such a degree that it requires additional management attention. The importance is exemplified by the \$600 million projected development and acquisition costs of ATE for the F-16. This amount of cost qualifies the F-16 ATE for major program status (25).

The role of support equipment has been recognized and numerous policies and regulations have been established for SE development and acquisition. Even with this guidance several problems have been identified with respect to evaluating alternatives in new SE acquisition and in controlling the cost of equipment already deployed in the field (23:1). One specific problem is that there is presently no proven method of estimating O&S costs of SE available to SE managers.

Statement of the Problem

There is a need for a model to estimate and measure Operating and Support costs for avionics Automatic Test Equipment that will be used in Life Cycle Costing techniques applied to ATE Support Equipment programs.

Background and Justification

The policy of the Department of Defense (DOD) in compliance with the Armed Services Procurement Act of 1947 is to procure supplies and services from responsible sources at fair and reasonable prices. Supplies and services procured under this policy should result in the lowest overall cost of ownership to the government (1:A5-1). One way to determine a fair and reasonable price is to employ Life Cycle Costing (LCC) techniques when acquiring new systems and equipment.

LCC "covers the entire cost spectrum from design, development and acquisition, through operating and support to ultimate equipment salvage [26]." LCC began in the Air Force in 1968 with the procurement of nonrepairable items and progressed in stages through applications to major subsystems to major weapon systems (26). Today LCC continues to expand within the Air Force. Depending on the intended use, LCC is "a costing discipline, a procurement technique, an acquisition consideration and a trade-off tool [14:39]."

In its use as a costing discipline, LCC deals primarily with O&S cost-estimating methods (14:39). O&S costs, those generally associated with ownership, include the costs of operation, maintenance, and general support (17:1). Since 1975 the DOD has placed increased emphasis on O&S costs in order to reduce total weapon system costs (6:ii).

One reason for this added emphasis is that O&S costs of a system will probably exceed the initial cost of acquisition. Additionally, O&S costing has been determined to be important in the areas of Force/Support Program Balance, Weapon Systems Comparisons, Historical Cost Perspective, and Design to Cost Implementation (31:2-4). While O&S costs have generally been associated with complete systems, the same benefits of these types of analysis can be applied to acquisition below the system level such as SE.

According to the Logistics Management Institute, the Air Force is procuring SE at the rate of \$1 billion per year and investments in SE are projected to increase (25). As noted previously, ATE is becoming a significant factor in total SE costs. ATE is defined to include all

Electronic devices capable of automatically or semi-automatically generating and independently furnishing programmed stimuli, measuring selected parameters of an electronic, mechanical, electro-mechanical, or electro-optical item being tested, and making a comparison to accept or reject the measured values in accordance with predetermined limits [1:A2-2].

Recently, acquisition of SE has received high-level attention due to large expenditures in this area. The General Accounting Office, the Inspector General, and the Logistics Management Institute have documented SE acquisition problems in the areas of high cost, untimely delivery, inadequate trade-off analysis, and unrealized standardization potential (25).

One of the earliest attempts to improve management of ATE O&S costs was in June 1971 when the Air Force Logistics Command (AFLC) directed San Antonio Air Logistics Center (SA-ALC) to prepare a plan to identify and quantify the cost elements involved with Air Force ownership of ATE. As stated in its scope, the model developed by SA-ALC only documents costs of ATE procured by the Air Force and is not a predictive model which lends itself to sensitivity analysis (1:5A-1).

Presently, the Aeronautical Systems Division SE System Project Office indicated that there is a need for an O&S cost model which could "help program managers forecast SE requirements, estimate budgets and schedules, and perform trade-off analysis [25]."

Research Objective

The objective of this research was to develop a model to estimate and measure O&S costs for avionics ATE which could be useful in LCC techniques applied to ATE Support Equipment programs.

Research Questions

The following research questions were posed to guide the research toward the stated objective:

1. What are the variables that contribute to the operating and support costs of ATE?

2. To what categories of operating and support costs do these variables apply?

3. What is the relationship among these variables that defines operating and support costs?

4. How sensitive are operating and support costs to changes in these variables?

CHAPTER II

LITERATURE REVIEW

A literature review of appropriate regulations, manuals, directives, and other publications was conducted to evaluate and/or define the following areas:

1. Models in general.
2. Mathematical models being used in the Air Force.
3. Accounting models and their use in the Logistics field.
4. AFLC O&S and Logistics Support Cost (LSC) models, techniques, and uses.
5. Logistic Support Cost Commitments (LSCC) techniques.
6. Elements to be considered in the development of a mathematical model for the estimation and measurement of the O&S costs of ATE.

Models

One of the aspects of man's reasoning faculty is the ability to predict what is going to happen; i.e., the ability to forecast.

Rational conduct depends not only upon knowing what is really happening and being able to interpret it, but on having present in our minds a representation of what is going to happen next [5:100].

This prognosis may often be inaccurate, but is continuously corrected by feedback. A mental representation or an abstraction of the real world is what can be called a model of the real world. This representation may be more or less accurate, that is, a more or less predictive aid in the behavior of the real world. "Because they are predictive, models are open to experimentation as a means of evaluating the likely performance of the thing modelled [5:100]."

The process of modeling is a process of mapping a conceptual model into a scientific language. During this process some conceptual richness is lost, because this conceptual richness depends on nuance, association, and mood, and it is not transferable into scientific terms. Nevertheless, a conceptual homomorphic scientific model is obtained that is precise and unambiguous (5:112-113). Because reality is in many cases too complex to be exactly reproduced, or because certain variables are irrelevant to a specific problem, models are simplified abstractions of the real world; that is, various degrees of abstraction can be obtained in modeling (28:20).

According to the degree of abstraction, models can be scale models, analog models, or mathematical models. Scale models, with the least degree of abstraction, are a physical replica of reality. Analog models are physical models that do not look like the real thing but behave like the thing modeled. Mathematical models use symbols

to represent the complexity of relationships in some systems.

Mathematical Models

Mathematical models typically are presented in the form of mathematical equations that establish the relationships between the variables. These models are easy to manipulate for the purpose of experimentation and prognosis. The dependent variables of the mathematical models tell how well a system performs, that is, reflect the level of effectiveness of the system. The independent variables of the model can be divided into two classes: controllable from the point of view of the decision maker (decision variables), and uncontrollable (28:20-23).

From the standpoint of the decision maker, models can be divided into normative and descriptive models. Normative models are usually optimum models that prescribe the course of action, while descriptive models reflect the system's performance under various input sets of data; descriptive models do not guarantee optimal solutions (27:30-39).

Models can further be deterministic, if certainty is assumed; and stochastic or probabilistic models, if uncertainty exists (27:75).

Logistics Models

There is an interface between the logistics area and Air Force system design; this interface involves three broad decision situations:

1. Conceptual design/concept evaluation.
2. Detailed system design.
3. Support planning.

When models are applied to solve Air Force logistics managerial situations they are called Logistics Models.

During the conceptual design phase logistics models can handle the comparison of "different concepts for achieving some set of performance characteristics or operational objectives, and for establishing envelopes for system characteristics [24:6]." During the detailed system design phase logistics models can handle the selection of a particular hardware design from a number of alternatives. Finally, during the support planning phase logistics models can handle the estimation of the kind and amount of resources required to support a particular design. A particular logistics model could very well be used for all three phases.

There are many logistics models developed and used in the logistics field. They can be categorized, depending on the methodology they use, as analytical or simulation models. Analytical models "yield a single answer or a unique set of answers for any given set of values of input

data [24:10]." The solution that this type of model gives is the desired consequence sought, and it requires a minimum of computation. Most of the logistics models fall within the analytical category. Simulation models are appropriately employed for systems characterized by large data bases or sizable solution sets (24:10); that is, when the situation is too complex for the use of analytical models. When dealing with complex situations, however, simulation models do not necessarily give optimal solutions; what they furnish is an approximation to the best answer. Even with a good selection of input data the optimal solution is not assured. Simulation models are more expensive than the analytical ones, and present difficulties in debugging and validation.

The analytical models can further be categorized into probability models, network or flow models, and accounting models. Models, like the reliability models, that are based on the probability of occurrence of events, are called probabilistic or probability models. When the situation involves movement of things, like materials, spares, or reparable, flow models are best suited. Accounting models are commonly used in the logistics field because resources are usually expressed in terms of dollars. They are "a structured way of adding component costs [24:12]." The accounting models used in logistics compute the operating and support costs at relatively low

levels of hardware breakdown--Line Replaceable Units (LRUs)-- and total these costs. They include initial and replenishment spare costs, on- and off-equipment maintenance costs, inventory costs, support equipment costs, cost of personnel training and training equipment, cost of management and technical data, and cost of new facilities. As we shall see, the model developed in this research effort falls into this class of logistics model.

Life Cycle Cost Models

The life cycle cost models include a variety of mathematical models that "address some aspect of life cycle costing during the weapon system acquisition cycle [8:1]." They translate system characteristics and performance into requirements for support resources, and ultimately into dollar cost estimates. Life cycle cost models are used for:

1. Computation of Operating and Support cost estimates which are taken as decision criteria by DSARC or other levels of management.
2. Computation of Operating and Support cost targets which are incorporated into contractual commitments, and to measure success in meeting such targets.
3. Computation of comparable Operating and Support Cost estimates for consideration during source selection.

4. Trading off alternative equipment designs and support concepts on the basis of their impact on life cycle cost (8:1).

The link between system design and the cost to operate and support the equipment resulting from that design can be established by: (1) making a good estimate of the operational and support costs during the acquisition process; (2) keeping records of the costs of operating and maintaining the system in the field; (3) finding out what operating and structural characteristics of the system drive the costs for O&S; and (4) feeding back what DOD learns to the industrial community so they can improve design from an O&S cost impact viewpoint (31:4).

Life cycle cost models do have utility in the Integrated Logistics Support (ILS) context, as tools to:

1. Study the impacts of operational requirements on design and support alternatives.
2. Identify areas of high support costs as a consequence of design decisions.
3. Make useful comparisons of alternative support postures.
4. Develop budget estimates.
5. Act as evaluation tools in the source selection process and to define incentive goals and other contract guarantees (24:30).

Comparing operating and support costs of a new system with the O&S costs of current systems permits one to:

1. Determine trends in O&S costs.
2. Determine shifting demands for support resources among similar systems.
3. Focus management attention on critical resource demands of the new system (31:3).

The most important reason for evaluating O&S cost impacts of a new system is the need for DOD to implement the Life Cycle Cost concept, that is, the integration of O&S cost targeting and weapon system design (31:4).

There are several types of LCC models: Cost Factor Models, Cost Estimating Relationship Models, Economic Analysis Models, Logistics Support Models, Reliability Improvement Cost Models, Level of Repair Analysis Models, Maintenance Manpower Planning Models, Inventory Management Models, and Warranty Models.

The following are desired characteristics of LCC models:

1. Completeness--LCC models must include all elements of life cycle cost appropriate to the decision issue under consideration.
2. Sensitivity--LCC models must be sensitive to the specific design or program parameters under study in order to resolve life cycle cost differences between alternatives.

3. Validity--LCC models are abstractions of the real world and some judgment will be required with respect to how valid cost estimates are.

4. Availability of input data--LCC models should use data that are readily available at low cost and have a high level of accuracy.

LCC models developed up to now present the following deficiencies:

1. There are certain parameters not taken into account by such models. Models are not sensitive to certain performance and design parameters, such as accuracy, speed, range, and, as one author has pointed out, "Early tradeoff decisions frequently have large impacts on O&S costs [8:24]."

2. In many cases, LCC models are too complex. They may have a large number of parameters which may obscure a small set of parameters that are more relevant to life cycle cost. Also, the definitions of the parameters are often unclear.

3. In many cases input data are not available on time, are expensive to collect, or lack the desired level of confidence.

4. Some LCC models are not sensitive to wear-induced failures (8:8-9).

Generally speaking, a model must be oriented to a relatively narrow range of application in order to be

useful for analysis of a specific design issue. Input data must be relatively easy to obtain.

General purpose LCC models tend to be inadequate for specific applications because they (a) lack resolution with respect to specific decision issues, (b) do not reflect characteristics of peculiar equipment types, (c) require data in formats that are too extensive or are not compatible with formats of available data [8:4].

Logistics Support Cost Commitments (LSCC) Technique

LSCC is a relatively new technique that contractually embodies the concept of aggregate target cost for measuring O&S costs, and provides incentives to the contractor to lower O&S costs. This technique has been used in only a small number of contracts and its effectiveness requires more evaluation. However, LSCC is an innovative technique that if applied on a selective and controlled basis will broaden the Design to Cost (DTC) concept to include the operating and support cost in addition to the development and production costs already encompassed.

The Design to Cost concept, which has been implemented with success by the DOD, is defined in DOD Directive 5000.28 as

. . . a management concept wherein rigorous cost goals are established during development and the control of systems costs (acquisition, operating, and support) to these goals is achieved by practical tradeoffs between operational capability, performance, cost, and schedule. Cost, as a key design parameter, is addressed on a continuing basis and as an inherent part of the development and production process.

Also, DOD Directive 5000.28 establishes the need for measurable operating and support cost goals "which can be monitored during test and evaluation as well as in operation [13:3]."

One way to measure operating and support costs is in terms of dollars. In order to do this, ". . . it is necessary to convert the measures of reliability and maintainability, such as MTBF and MTTR into expressions of cost [13:24]." The LSCC technique takes into account these cost goals in terms of dollars, and uses the following three elements to determine achievement of these goals:

1. A target logistic support cost (TLSC), defined according to a LSC model framework.
2. A measurement and verification of the LSC.
3. A remedy or price adjustment, according to the results of the measurement and verification of the LSC.

Framework for an LSC Model

In the Logistics Support Cost Commitment Technique the government logistics support costs, as a function of contractor-controllable equipment logistic parameters, are represented by a simplified cost model. This cost model is structured in line with the recommendations of the Joint Logistic Commanders' Design to Cost Guide (30:23-24).

The cost model has two kinds of parameters: those parameters, such as MTBF and Not Repairable This Station

(NRTS), over which the contractor has certain control through his engineering design, and other parameters that describe the environment in which the equipment is to be operated and maintained. The latter parameters are supplied by the government with the model framework (9:2).

The cost model framework is developed by the program office or acquisition management staff personnel and is given to the interested contractors as part of the LSCC provisions. This cost model framework will become the basis for the negotiated contract, and for formal communication between contractor and government (9:3). An outline of a basic LSC model framework is presented in Appendix A.

Target Logistics Support Cost

A cost target within the LSCC has several benefits. First, the LSCC contractual technique provides great design flexibility to the contractor permitting LSC reduction to the government. The contractor has many alternatives to lower the logistic support cost as long as he can meet the target logistic support cost (TLSC) (9:3). Second, the logistic support cost impact of the interactions among logistic parameters is reflected in the cost model framework. This impact cannot be detected if reliability and maintainability targets are set individually. Looking at the mathematical model, it is easy to see how costs can be changed by increasing or decreasing a parameter, such as

MTBF or NRTS. Third, cost impact is in terms of dollars, facilitating "effective analysis of trade-offs between acquisition cost and LSCC impacts of equipment design expenditures [9:3]." Fourth, it is easy to perform sensitivity analysis.

The cost model framework (CMF) could be expanded to incorporate other parameters and all possible interactions, but "as the accuracy and comprehensiveness of the CMF is enhanced, its mathematical complexity increases [9:5]." As the complexity of the CMF increases, the responsibilities under the LSCC become more difficult to determine; risk becomes much harder to assess, and incentives decrease.

Implementation Considerations

Since LSCC is an important and complex legal document, several managerial decisions require considerable attention in the implementation of the LSCC. For example, it is very important for the verification environment to be fully defined. Failure definition, parameter estimate definition, and responsibilities of both the government and contractor must be clearly stated and must include considerable detail. The LSCC must include all kinds of detail and definitions relevant to determining the method to be followed during the verification stage, and any kind of adjustment in the TLSC prior to the verification test.

Another important consideration is the development of contract adjustment procedures. From the comparison of the measured logistics support cost (MLSC) and the target logistics support cost, contract remedies or price adjustments are made. If $MLSC < TLSC$, positive adjustment can be used. An award fee as a function of the difference between MLSC and TLSC, up to a specified value, is one method of positive adjustment. An increment of the price per unit as a function of the difference between MLSC and TLSC is another way of positive adjustment. If the $MLSC > TLSC$ by a certain percentage, usually 10 percent, the LSC performance of the equipment is not adequate, and remedies are used (9:7).

If the $MLSC = TLSC$ or they differ only within a small specified percentage, it is regarded as sufficient compliance of the LSC target by the contractor, and the contractor is given the benefit, e.g., award fee. All price adjustments or remedies must be conducted according to what is specified in the LSCC (9:7).

Another consideration is related to the kind of risk that the LSCC exposes both the contractor and government to. Cost risk is part of business risk, and has two elements--statistical risk and technical risk. Statistical risk is the risk of making incorrect award/remedy decisions because of differences between the MLSC and the LSC of the underlying true population. Statistical risk

considerations are necessary because MLSC is only an estimate of the true measured logistics support cost of the underlying population. Technical risk is the risk due to variability of the possible values of the MLSC of the underlying population relative to the target logistics support cost. This technical risk is a function of the state of the art, the efficiency of the manufacturing process, the compliance with the development schedule, and other technical factors. Statistical and technical risks both have a significant impact on the LSCC as a tool for the transmission of incentives to the contractor (9:9).

If the statistical risk is very high, incentives are reduced, and needless expenditures may be incurred if equipment is rejected when it meets the requirements, or if equipment is accepted when it should be rejected (9:9). When the technical risk is very high or the variability of the true MLSC of the underlying population is very large, the use of the LSCC technique is not recommended (9:9).

Other considerations are related to the legal aspects of the LSCC. The contractor's responsibility for various factors of LSC has to be balanced against sufficient authority to control those factors of the LSC; and the government has to guarantee the maintenance of the prenegotiated levels of those factors over which the contractor has no control (9:9).

Since both contractor and government are interested in having low statistical risks, one way to reduce statistical risks is by using the LSCC for a group of items: developing a TLSC for the aggregate of items instead of separate TLSCs for each individual item. Statistical risk reduction is due to the existence of independence of variability of test data among items.

Two problems may arise in trying to lower statistical risk with the aggregation over several items. First, if the prime contractor passes down to subcontractors the same LSCC provision on an item-by-item basis, subcontractor's statistical risk may be very high. Second, during the verification test, some items may have very high MLSC, but the aggregate target may be met due to the "offsetting effect of low measured LSCs for the remaining items [9:15]." These high MLSC items may be the cause of weapon systems down time in the field.

Of prime consideration is the research that has to be done when structuring the LSCC. The purpose of the LSCC technique is to maximize contractor incentive to reduce government LSCs while maintaining statistical risk to contractor and government at acceptable levels. Thus the assessment of the values that will establish the relationship among the control parameters has to be made in a rigorous manner. If these values are realistic, the Cost Model Framework (CMF) will adequately represent the costs

of logistic support for the actual equipment demand. If control parameters are well set and their relationships well defined, it will "permit extensive studies of trade-offs among the four parameters [9:17]." It also will permit enough time to study the LSCC statistical risk prior to negotiation of terms and conditions of the LSCC.

The LSCC technique is a well conceived and innovative contracting technique. It appears to be an effective way to transmit to the contractor DOD life cycle goals.

The CMF is a simplified model that represents government LSCs as a function of contractor-controllable equipment logistic parameters. Nevertheless, the LSCC needs certain prerequisites in order to be recommended as an adequate contractual technique: statistical and technical risks have to be low enough so that contractors are attracted to work on a project and so that LSCC effectiveness in transmitting incentive to the contractor to design a reduced LSC item of equipment can be maintained. However, the LSCC techniques have been used in only a small number of contracts and need a more complete evaluation. "Future applications should be on a selective and controlled basis [9:17]."

The Logistics Support Cost model was the type of model developed for the estimation and measurement of the O&S costs for avionics ATE. This model concept permits the utilization of the LSCC technique for contractual

commitment purposes. The reasons for selecting this model and the LSCC technique approach were:

1. LSC models are designed to support the technique of life cycle costing.
2. LSC models are very useful in source selection.
3. The LSCC technique transmits DOD life cycle cost goals to the contractor.
4. The LSCC technique is in line with the DOD "Design to Cost" concept.

Logistics Support Cost Model for Automatic Test Equipment

The logistics support cost model for automatic test equipment developed in this study is a representation of the real world expressed mathematically. The model can serve as an aid in the decision-making process and help reduce the risks associated with uncertainties of the future (19:77).

The model consists of a set of mathematical equations representing different operation and support cost elements. Summation of this set of equations yields the approximate operating and support cost for automatic test equipment over a specified period of time.

Reliability and Maintainability

The two primary factors which determine operating and support cost are reliability and maintainability.

According to AFLCP 800-3,

. . . reliability is the principal performance factor influencing design and life cycle support costs. It predominates as a lead factor in determining other factors such as availability, maintenance load factors, and spares and support requirements [2:7].

Increased reliability could result in decreased operating and support costs but probably at a higher acquisition cost. Maintainability is a quantification of the ease of maintenance. "Maintainability is a consideration of design, while maintenance is a consequence of design [2:11]." Designing ease of maintenance into a product may also result in reduced operation and support costs, but again may increase acquisition costs. These two factors (reliability and maintainability) illustrate the necessity for a model in which acquisition costs can be weighed against operating and support costs in determining the "best buy" for the government. Thus it was important to understand the relationship between reliability and maintainability and operation and support costs.

Assumptions and Limitations for Model Development

Basic assumptions and limitations necessary for model simplicity in developing the automatic test equipment operating and support cost model were as follows

(10:4):

1. Each base of operation using the automatic test equipment was considered to be fully operational.

2. The spares requirement was based on the highest level of program activity.

3. Only one Technology Repair Center (TRC) location and several intermediate base repair locations were considered.

4. Only recurring training for maintenance personnel was used.

5. Certain factors that contribute to operation and support costs were not considered due to lack of estimates or difficulty in evaluating such costs. Examples of these factors are modification costs and software changes.

Factors of the Logistics Support Cost Model

The logistics support cost factors considered in the automatic test equipment model are:

1. Cost of Test Replaceable Unit (TRU) Spares (C_1)
2. On-Equipment Maintenance (C_2)
3. Off-Equipment Maintenance (C_3)
4. Inventory Management Cost (C_4)
5. Cost of Support Equipment (C_5)
6. Cost of Personnel Training (C_6)
7. Cost of Management and Technical Data (C_7)
8. Calibration Requirements (C_8)

Logistics support costs are the sum of all factors included in the model; e.g.,

$$\text{ATE Logistics Support Cost} = C_1 + C_2 + C_3 + C_4 + \\ C_5 + C_6 + C_7 + C_8$$

The cost factors are discussed individually in order to gain more insight into the logistics support cost model.

Cost of TRU Spares. The logistics support cost model provides for a systematic determination of the types and quantities of spares and repair parts required to maintain and support the automatic test system and its associated hardware for a fixed period of time. The equipment spares are necessary to fill the field and depot repair pipelines and to replace the items which are condemned at base level over the life of the system. The base repair pipeline spares include a safety stock to protect against random fluctuations in demand (10:3-1).

On-Equipment Maintenance. On-equipment maintenance includes servicing, preventive maintenance, time change removals, and unscheduled removals. On-equipment maintenance for automatic test equipment is done at the intermediate level. This cost factor also includes the time expended during fault-isolation to a subassembly level.

Off-Equipment Maintenance. Off-equipment maintenance is associated with the repair of subassemblies after removal from the automatic test equipment when a failure has occurred. Off-equipment costs are estimated using the

average value of labor where the average cost to repair includes the cost of labor (salaries, fringe benefits, overhead and lost time) employed in the repair process (7:44). Erroneously removing a properly functioning subassembly will also be included as part of this cost. Off-equipment maintenance can be accomplished at the intermediate level where one facility provides support to one or more using organizations or at the Technology Repair Centers (TRCs) which possess more sophisticated equipment and greater maintenance capability. Repair at two different maintenance levels can cause confusion in determining cost of off-equipment maintenance since the costs to repair at base level are different than the costs at the TRC level.

Inventory Management Costs. This element of cost is considered as the new inventory life cycle management cost based on the number of spares estimated under the spares cost factor (7:33).

Cost of Support Equipment. This cost factor includes the quantities and costs to acquire and maintain new peculiar items of TRC and base shop equipment utilized in the repair of automatic test equipment (10:3-7).

Cost of Personnel Training. This factor includes the cost to train base and depot maintenance personnel over the life of the automatic test equipment (10:3-10).

Cost of Management and Technical Data. This cost factor includes the labor costs associated with the preparation of maintenance forms due to equipment failures and scheduled or periodic maintenance. Also included are the costs to acquire and update technical orders and other technical data (10:3-11).

Calibration Requirements. Calibration requirements are a cost factor that is unique for test equipment. This element includes the cost of calibration of all items that require it on the automatic test equipment. Calibration intervals, calibration time, and equipment turnaround are important items affecting this cost factor.

Summary

There is a definite need for management tools which can aid the Air Force manager in decision making in this time of tight money and ever-increasing weapon system costs. The life cycle costing technique is one of the management tools which has been employed successfully in reducing system costs.

There are different models which have been developed and used in life cycle costing. Some of the models are the life cycle cost models, logistics support cost models, and operation and support cost models. Unavailability of support equipment models has resulted in poor cost reduction results and has invoked criticism of systems acquisition.

Life cycle costing techniques have not been applied to all Air Force systems acquisition. Such is the case in the area of support equipment acquisitions and especially in the automatic test equipment arena where increasing cost has focused high level attention. Consequently, it was the intent of this research effort to develop a logistics support cost model for automatic test equipment that could prove useful in ATE life cycle costing applications.

CHAPTER III

METHODOLOGY

This chapter describes the methods which were used to answer the following research questions:

1. What are the variables that contribute to the operating and support costs of ATE?
2. To what categories of operating and support costs do these variables apply?
3. What is the relationship among these variables that defines operating and support costs?
4. How sensitive are operating and support costs to changes in these variables?

The research followed the steps outlined in Figure 1 to address the areas of variable identification, variable relationships, and model sensitivity. Research question number 1 was answered by comparing existing O&S models with actual data collected from the depot and field. Examination of the variables and personal judgment was used to categorize the variables identified to answer question number 2. An adaption of dimensional analysis was used to answer question 3. Question 4 was addressed by a mathematical computer analysis of the model variables.

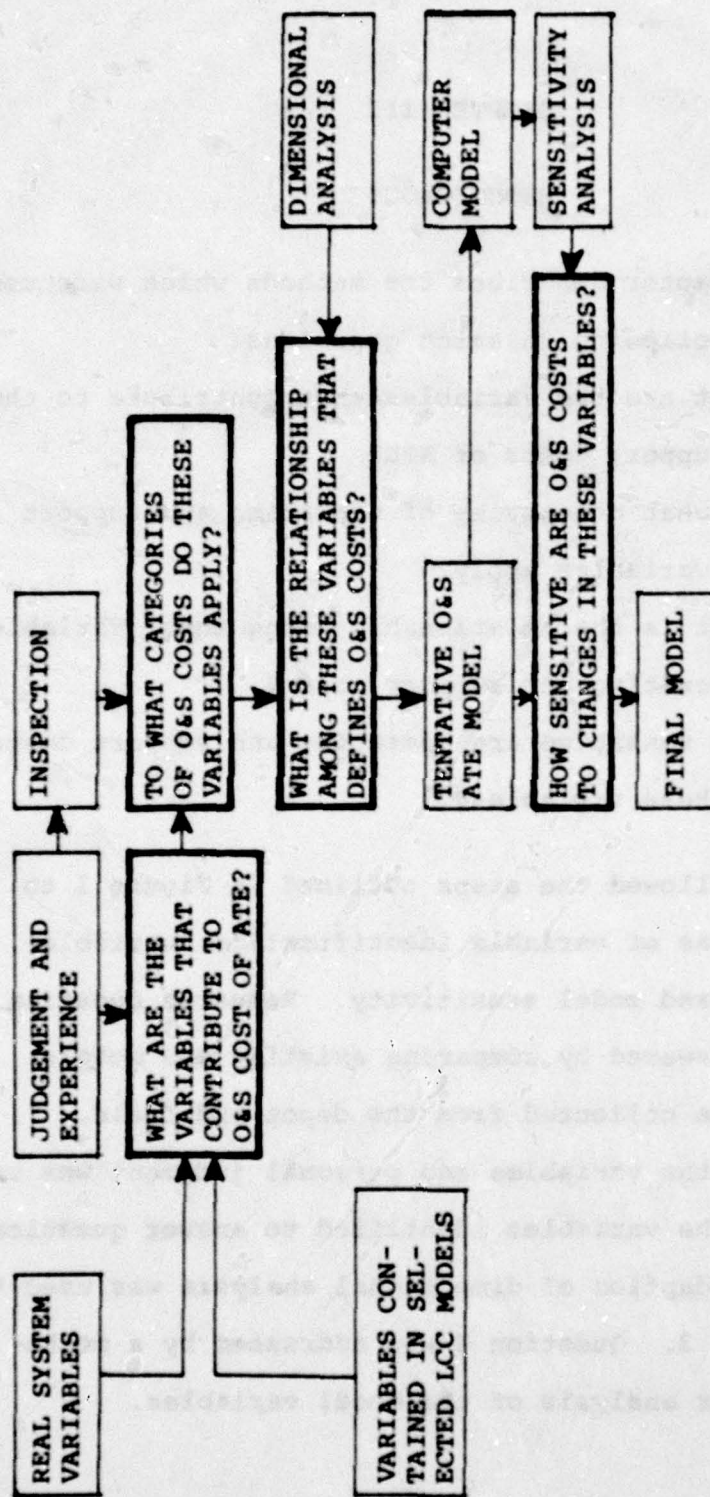


Fig. 1. Steps Included in Methodology

Data Base and Data Validity

The primary data used in the selection of the model variables and for validation of the model was obtained from the following sources:

1. San Antonio Air Logistics Center (SA-ALC)
2. Air Force Logistics Command Headquarters (AFLC)
3. Newark Air Force Station, Ohio (AFLC/AGMC)
4. Air Force Acquisition Logistics Division (AFALD)
5. DCASPRO Bendix Corporation

Spares requirement data and depot maintenance data were obtained from San Antonio Air Logistics Center (ALC) and DCASPRO Bendix Corporation. San Antonio is the prime ALC responsible for all Air Force Automatic Test Equipment and Bendix Corporation is the prime contractor for F-15 ATE. The system manager, item manager, and contractor for ATE supplied the necessary historical data which were used to determine the variables that contribute to the majority of operating and support cost. The contractor and depot maintenance actions performed provided an indication of those variables responsible for driving the maintenance component of the operating and support cost. Typical data gathered from SA-ALC and Bendix were spares cost, number of failures, mean time to repair, depot costs, ATE operating time, and contractor costs.

The field maintenance data available at HQ AFLC were retrieved from the USAF Maintenance Data Collection

System commonly called 66-1 data. The data sources were the DO56 and DO41 management information systems. Typical field maintenance data reported by Work Unit Codes (WUC) were the maintenance action performed, manhours to repair, and when failure occurred. These maintenance data were initially recorded by the maintenance technician effecting ATE LRU repair and were documented in accordance with AFM 66-1. Repair at the field level was charged against a particular WUC which is a hierarchical parts identification system which identifies every reparable or major component in the ATE (29:11-002).

Data pertaining to calibration intervals and calibration times for ATE were obtained from Newark Air Force Station (AFLC/AGMC), which is responsible for calibration equipment. The manhours expended to remove or replace equipment that was sent for calibration were charged to the field maintenance activity and were included in the field level data. However, the actual time required to calibrate each component at either the Precision Measurement Equipment Laboratories at the depot or the contractor was gathered by AFLC/AGMC.

The data pertaining to the different Logistic Support Cost models were obtained from the Air Force Acquisition Logistics Division at Wright-Patterson AFB. These data were necessary in studying the variables presently being utilized by the existing models and providing a

basis for standardization of variable symbols and nomenclature.

Since the only sources of data for the research were from Air Force agencies and data systems, it was assumed that the data were accurate and valid for the intended purposes of variable selection and validation of the operation and support cost model. All data, once collected, were classified as either nominal, ordinal, interval, or ratio in accordance with the guidelines outlined by Emory (15:113-117).

Existing Model Variables

Three of the existing operating and support cost models were studied to determine the variables being used and their symbols and nomenclature. This was necessary to take advantage of existing computer programs that were modified in order to perform the mathematical analysis of the proposed operation and support cost model.

One of the models studied was the AFLC Logistics Support Cost (LSC) model. This model is an applied cost analysis technique which is general purpose in content and is not appropriate for all systems and categories. The LSC model must be tailored for use on particular systems and equipment (10:4). The program for this model is available on the AFLC CREATE computer system. Another model that was studied was developed by the Operations Analysis

Office at HQ AFLC under the name Project ABLE (Acquisition Based on Consideration of Logistics Effects). Project ABLE is an effort "directed towards creating tools which measure the logistics consequences of Reliability and Maintainability and applying them so as to make new weapon systems better--sooner [21:1]." An actual application of an operating and support cost model to the F-4E aircraft program was also studied to determine actual variables used. The model is the A-X ten-year operating and support cost model (7:1).

Variables Used in Actual Cost Data

A study was undertaken to determine what variables are presently being used in computing actual operation and support costs. The following groupings of variables were among those considered in the study:

1. Depot cost variables
2. Field cost variables
3. Calibration cost variables
4. Spare cost variables

These cost areas commonly represent the actual O&S costs that are currently being recorded.

The variables making up the depot cost were, for example, cost to repair, depot pipeline spares, and depot time to repair. These data were obtained from the ATE system manager at SA-ALC/MMI division and DCASPRO Bendix

Corporation. The field cost variables consisted of on and off equipment maintenance done on the ATE. This included such maintenance actions as: time spent on adjustments of the ATE, removal or replacement of components, and actual troubleshooting time. The calibration cost data were obtained from AFLC/AGMC at Newark AFS, Ohio. These data pertained to: calibration intervals, calibration times, and cost of calibration. The last area of cost considered was the amount and cost of spares necessary to support a particular piece of ATE.

Selection of Variables

The determination of variables for the operating and support cost model was made by comparing the variables presently being used on other operating and support cost models and the variables which are actually contributing to O&S costs of Automatic Test Equipment.

The first step in the comparison was to list all variables found in existing O&S cost models and variables observed in actual data. Once listed, an attempt was made to match each variable, one for one, between the existing models and actual data. If a direct match was possible the variable was tentatively included in the model. When a direct match was not possible, as was the case when the existing model contained variables not found in existing data or vice versa, an evaluation based on the strength of

the variable was made to judge whether it should be included. Only those variables which collectively contributed approximately 80 percent to the actual operating and support cost were considered for inclusion in the ATE operating and support cost model. This decision was based on the value volume concept originally observed by the Italian economist, Pareto, who based his findings on the fact that a few items usually account for the majority of the value of a system (28:159).

Relationships of Variables

The categories of variables for the proposed model were found to be similar to those found in existing O&S models. Examples of variable categories are off-equipment maintenance, on-equipment maintenance, and spares requirements. A more complete list of categories is found on page 26 in the list of factors considered in the model. The categories of variables was determined through examination and personal judgment. The relationships among the variables were determined by personal experience, dimensional analysis, and in some cases, adaption of dimensional analysis.

Dimensional analysis is a method of specifying the form of the functional relationship between a number of variables if and when we know that just one relationship must necessarily tie these variables together (12:4-5).

For the purpose of the development of a mathematical model that predicts the O&S costs for ATE, dimensional analysis technique was applied in finding the functional relationships between the selected variables. Dimensional analysis enabled us to find the variables that must enter the relationship in certain definite combinations. In our model, where dimensional analysis was used variables selected were grouped in categories representing partial O&S costs; then, dimensional analysis was applied to this category. For example, if C_3 is a category representing off-equipment maintenance cost, the dimensional analysis technique would allow us to find C_3 as a function of several variables such as manhours (X_1), operating time (X_2), and cost per manhour (X_3). Thus, $C_3 = f(X_1, X_2, \dots, X_n)$, where X_1, X_2, \dots, X_n represent the selected variables that go into the functional group or category. Further, the dimensional analysis technique would help to determine the X_i that best dimensionally combine to yield the C_3 value. The relationship between these variables was also determined with this technique; i.e., the relationship that maps the independent variables into the dependent variable.

Sensitivity Analysis

Once the ATE operation and support cost model was developed, the final task was to insure that all the important independent variables were included in the model

while at the same time, insuring simplicity of the model. A computer program was developed to calculate the changes in the dependent variable when each independent variable value was changed through an entire range of values. The ranges of the independent variable values were established by inspection and by consulting experts. A computer run was performed for each of the independent variables.

The purpose of this sensitivity test was to determine the relative driving effect of each of the independent variables. This analysis allowed us to decide whether a variable should stay in the model or whether it should be dropped from the model.

CHAPTER IV

MODEL DEVELOPMENT

As stated earlier in Chapter I, the objective of this research was to develop a model to estimate and measure O&S costs for avionics ATE which could be useful in LCC techniques applied to ATE support equipment programs. More specifically, the model was developed with the intent that it be used primarily as an aid in source selection and as a means of defining incentive goals and other contract guarantees. Thus, the accounting type model appeared most appropriate for these purposes and model development was aimed at producing this class of model. The model was not intended as a means of predicting operating and support costs based on design parameters (e.g., range, weight, thrust, etc.), nor was it envisioned as a means of estimating total life cycle costs. Estimating total life cycle costs would require a model which incorporated all elements of life cycle cost. As stated earlier, this model development effort considered only high cost drivers and omitted ATE software costs due to data unavailability.

Data availability is, of course, a primary consideration in model development and use. The model described in this thesis contains variables whose values can

be determined by the analysis of data available through various government and contractor sources. However, in the early stages of weapon system acquisition--prior to selection of a full scale development (FSD) contractor--many of the estimates required to be made of variables in the model can only be made with a reasonable degree of accuracy by the competing contractors. Thus, the model should be provided to the contractors and employed by them initially to set target logistics support costs (TLSCs). The government would then use the model subsequent to FSD to determine measured logistics support costs (MLSCs). This comparative characteristic of model use eliminates the necessity for the model to contain all elements of life cycle cost.

With these thoughts in mind, the remainder of this chapter describes the way in which the model was developed.

Steps in Model Development

A model was developed using the following categories (previously defined in Chapter II):

- C_1 = cost of TRU spares
- C_2 = on-equipment maintenance cost
- C_3 = off-equipment maintenance cost
- C_4 = inventory management cost
- C_5 = cost of support equipment
- C_6 = cost of personnel training

C_7 = cost of management and technical data

C_8 = cost of calibration

For development of this model it was assumed that the contractor would be given the weapon system First Line Unit (FLU) testing requirements and that no TRU would be repaired at field level. The steps that were followed in the development of the model were: identification of the variables, grouping of the variables into the different categories and determining their relationships to obtain the category equation, and finally combining all of the categories to obtain the overall O&S cost model for automatic test equipment. The AFLC Logistics Support Cost Model was used as a guide in development of this model (10).

Identification of Variables

The identification of variables consisted of listing all the variables obtained from actual data, i.e., depot, field, PMEL, and comparing them to the variables used in other models. Variables that were found in actual data and were used in other models were selected as candidates for the proposed operation and support cost model. A matrix, shown in Appendix B, was developed to show this comparison. The explanation of each of the variables is presented in Appendix C. A direct match between all of the variables from actual data and from other models was not

possible in all cases. A list of these variables and the justification for including them in ATE O&S models is as follows:

1. POH--monthly peak operating hours are important in determining the cost of TRU spares during a surge condition. Peak operating hours depend on the efficiency with which the contractor's equipment can meet surge weapon system testing requirements.

2. TARGAVAL--the target availability of the ATE would be furnished by the government and would be necessary to determine the appropriate number of spare TRUs that would minimize cost.

3. BCA/DCA--although the data for the total cost of additional items of common base (BCA) and depot (DCA) support equipment was not readily available, such data could be required of the contractor on new procurements. Depending on the type of ATE, this cost could be rather substantial.

4. DPA--the cost of the depot peculiar shop equipment could also be substantial and, although the data was not readily available, it could be part of the data furnished by the contractor on a new procurement.

5. DCOND--the actual data for the fraction of TRUs returned to the depot for repair expected to result in condemnation at the depot was not available from any of the present sources. However, the condemnation rate for some

TRUs could be very high and would have a great effect on the cost of TRU spares. The data for this variable therefore has to be obtained.

6. RIP--the data for the fraction of failures that can be repaired in place could not be obtained from actual data. This variable should be kept in the ATE O&S model as it contributes to the on and off equipment maintenance and can have an impact on the maintenance concept employed. The data could be required from the contractor on a new procurement.

7. Calibration Variables--the cost of ATE calibration was not found to be included in any available model. However, available data at both the field and AGMC level indicated that calibration costs represented a major cost input in the operation of ATE. An example of the importance of calibration was found in the dedication of unique calibration to support of F-15 ATE. A list of calibration variables considered is contained in Table 8, page 76.

Relationship of Variables by Category

In the development of the relationship of variables by category, two techniques were used. One was the modification of existing equations found in other cost models and the other was by using dimensional analysis. Equations C_1 , C_2 , C_3 , C_4 , C_5 , C_6 , and C_7 were derived by modifying existing equations from the AFLC Logistics

Support Cost Model (10). Dimensional analysis was used to derive equation C_8 .

Cost of TRU Spares (C_1). This equation, shown in Table 1, is used to calculate the cost of spares required to support the ATE over the life of the system. Spares are required to fill the depot repair pipeline, to replace condemned items, and to fill the base supply pipeline.

The spares necessary to fill the depot repair pipeline are computed as follows:

$$\sum_{i=1}^n \frac{(\text{POH}) (\text{QPA}_i) (1-\text{RIP}_i) (1-\text{DCOND}_i) (\text{DRCT})}{\text{MTBF}_i} \text{UC}_i$$

where $\frac{(\text{POH}) (\text{QPA}_i)}{\text{MTBF}_i}$ is the number of monthly failures for the i^{th} TRU, $(1-\text{RIP}_i)$ is the fraction of TRUs that cannot be repaired in place, $(1-\text{DCOND}_i)$ is the fraction of items which are not condemned, DRCT is the depot repair cycle time and UC_i is the unit cost for the i^{th} TRU.

The cost of spares necessary to replace the TRUs that will be condemned is as follows:

$$\sum_{i=1}^n \frac{(\text{TOH}) (\text{QPA}_i) (1-\text{RIP}_i) (\text{DCOND}_i)}{\text{MTBF}_i} \text{UC}_i$$

where $\frac{(\text{TOH}) (\text{QPA}_i)}{\text{MTBF}_i}$ is the number of failures for the i^{th}

TABLE 1

COST OF TRU SPARES (C_1)

$$C_1 = M \sum_{i=1}^N STK_i (UC_i) + \sum_{i=1}^N (POH) (QPA_i) (1-RIP_i) (1-DCOND_i) (DRCT) \frac{UC_i}{MTBF_i} \\ + \sum_{i=1}^N (TOH) (QPA_i) (1-RIP_i) (DCOND_i) \frac{UC_i}{MTBF_i}$$

STK - Number of spares of the i^{th} TRU required for each base plus safety stock

M - Number of bases

UC_i - Unit cost

POH - Peak operating hours per month

QPA_i - Quantity of like TRUs per system

RIP_i - Fraction of failures that can be repaired in place

$MTBF_i$ - Mean time between failures

$DCOND_i$ - TRUs condemned at the depot

DRCT - Depot repair cycle time

TOH - Total operating hours

TRU over the life of the system and $DCOND_1$ is the fraction of items that are condemned.

The base supply pipeline spares requirement cost is as follows:

$$M \sum_{i=1}^N (STK_i) UC_i$$

where M is the number of bases, UC_i is the unit cost for the i^{th} TRU, and STK_i is the number of spares required at the base to fill the demand of failed TRUs.

It is generally assumed that the mean demand for spares at the base follows a poisson probability distribution (10:3-2). In order to determine STK it is necessary to first determine the lead time demand. The mean demand rate is:

$$\lambda_i = \frac{(POH)(QPA_i)(1-RIP_i)}{(M)(MTBF_i)}$$

and the pipeline time, t_i , is the weighted average of order and shipping time (OST).

The demand for spares over the lead time would be $\lambda_i t_i$. The probability of X demand during time t , would be

$$P = (X | \lambda_i t_i)$$

The expected number of backorders (XBO_i) for increasing values of stock levels (STK_i) is:

$$XBO_i = \sum_{i=1}^n (X - STK_i) P(X | \lambda_i t_i)$$

The probability AV_i of a spare TRU being available when demanded is then calculated as follows (10:3-2):

$$AV_i = \left[1 - \frac{XBO_i}{(QPA_i)(UEBASE)} \right]^{QPA_i}$$

This value of AV_i is calculated for different values of STK_i and an index is generated which gives the difference of the different stock levels divided by its unit cost. This shows the increase in availability as a result of the increase in stock levels as a function of cost. The probability AV of any spare for the system being available when demanded would be

$$AV = \prod_{i=1}^n AV_i = AV_1 \cdot AV_2 \cdot AV_3 \dots AV_{n-1} \cdot AV_n$$

This assumes that each TRU is necessary to keep the automatic test equipment operational.

A target (TARGAVAL) for system spare availability is established and the calculated AV has to be equal to or greater than the TARGAVAL. When $AV \geq TARGAVAL$ the spares availability criteria has been met at the least cost. An

example to illustrate the above concept will follow.

Assuming a system with only one TRU, the spare requirements data as computed by the model would be:

WUC	DMDMEAN(λ_i)	XBO	AV	STK	DPIPE	TOTAL COND
FAAAO	.67	.18	.9129	1	21	7

System AV = .913

where DPIPE is the number of spares required for the depot pipeline and TCOND is the number of units condemned.

The target system availability was .9. Note that the system availability is the same as the TRU AV since there is only one TRU. The model was examined again using two TRUs with the following results:

WUC	DMDMEAN(λ_i)	XBO	AV	STK	DPIPE	TOTAL COND
FAAAO	.67	.18	.9129	1	21	7
FAABO	.02	.02	.9904	0	1	1

System AV = .904

Note that system AV = $AV_1 \times AV_2$.

The model was again exercised using three TRUs. The results were:

WUC	DMDMEAN(λ_i)	XBO	AV	STK	DPIPE	TOTAL COND
FAAAO	.67	.04	.9821	2	21	7
FAABO	.02	.02	.9904	0	1	1
FAACO	.44	.01	.9944	2	13	10

System AV = $AV_1 \times AV_2 \times AV_3 = .967$
 Target Availability was = .9

Note that in order to meet the target availability, FAAA0 availability and STK level were increased. The STK level of TRU FAAA0 was increased to 2 and this resulted in its availability AV increasing to .9821. The reason the STK for FAAA0 was increased rather than FAAB0 or FAAC0 was that it was more economical to increase the availability of this component in order to meet the target availability criteria. Having established the required STKs for N number of TRUs to meet the system availability requirement the cost can be found by

$$M \sum_{i=1}^N \text{STK}_i \text{UC}_i$$

where M is the number of bases and UC_i is the unit cost for the i^{th} TRU. The cost for all TRU spares would then be

$$\begin{aligned} & M \sum_{i=1}^N \text{STK}_i (\text{UC}_i) \\ & + \sum_{i=1}^N \frac{(\text{POH}) (\text{QPA}_i) (1-\text{RIP}_i) (1-\text{DCOND}_i) (\text{DRCT})}{\text{MTBF}_i} \text{UC}_i \\ & + \sum_{i=1}^N \frac{(\text{TOH}) (\text{QPA}_i) (1-\text{RIP}_i) (\text{DCOND}_i)}{\text{MTBF}_i} \text{UC}_i \end{aligned}$$

On-Equipment Maintenance Costs (C_2). The on-equipment maintenance cost equation C_2 , as shown in Table 2, pertains to the cost of all maintenance, both corrective and preventive, that is performed on the ATE without removal of any equipment.

The term,

$$\frac{(TOH) (QPA_i)}{MTBF_i}$$

refers to the number of failures of like items over the life of the ATE (TOH). The manhours expended per failure at base level consist of preparation and access manhours (PAMH), manhours to repair a failure in place (RIP) (IMH), and manhours to remove and replace a TRU sent to the depot for repair (1-RIP) (RMH); RIP being the fraction of TRUs which can be repaired in place. Therefore, the corrective maintenance costs for one TRU using a base labor rate of BLR is:

$$= \frac{(TOH) (QPA_i)}{MTBF_i} [PAMH_i + RIP_i (IMH_i) + (1-RIP_i) (RMH_i)] (BLR)$$

The corrective maintenance costs for (n) number of TRUs is

TABLE 2
ON-EQUIPMENT MAINTENANCE (C₂)

$$C_2 = \sum_{i=1}^N \frac{(TOH) (QPA_i)}{MTBF_i} \left[PAMH_i + (RIP_i) (IMH_i) + (1-RIP_i) (RMH_i) \right] BLR$$

$$+ \frac{TOH}{SMI} (SMH) (BLR)$$

TOH - Total system operating hours

QPA_i - Quantity of like TRUs within the system

MTBF_i - Mean time between failure

PAMH_i - Average manhours expended for preparation and access

IMH_i - Average manhours expended to perform corrective maintenance in place

RIP_i - Fraction of TRU failures which can be repaired in place

BLR - Base labor rate

SMI - Scheduled maintenance interval

SMH - Average manhours to perform scheduled maintenance

$$= \sum_{i=1}^n \frac{(TOH) (QPA_i)}{MTBF_i} [PAMH_i + RIP_i (IMH_i) + (1-RIP_i) (RMH_i)] (BLR)$$

The next element to be addressed is the cost of preventive maintenance which is,

$$\frac{TOH}{SMI} (SMH) (BLR)$$

where SMI is the interval between preventive maintenance actions, and $\frac{TOH}{SMI}$ is the number of preventive maintenance actions. SMH is the average manhours required to perform the preventive maintenance action, and BLR is the base labor rate. The total cost for all on-equipment maintenance would then be

$$= \sum_{i=1}^n \frac{(TOH) (QPA_i)}{MTBF_i} [PAMH_i + RIP_i (IMH_i) + (1-RIP_i) (RMH_i)] (BLR) + \frac{TOH}{SMI} (SMH) (BLR)$$

Off-Equipment Maintenance Costs (C_3). The off-equipment maintenance cost equation is shown in Table 3. C_3 includes the maintenance manhours to repair components

TABLE 3
OFF-EQUIPMENT MAINTENANCE (C₃)

$$C_3 = \sum_{i=1}^N \frac{(TOH)(QPA_i)(1-RIP_i)}{MTBF_i} \left\{ [(DBCMH_i)(DLR) + (1-DCOND_i)((DMH_i)(DLR+DMR) + (DMC_i)(UC_i))] + 2[(PSC)(1-OS) + (PSO)(OS)](1.35W_i) \right\}$$

TOH - Total operating hours

QPA_i - Quantities of like TRUs in a system

RIP_i - Fraction of TRU failures which can be repaired in place

MTBF_i - Mean time between failure

DBCMH_i - Average time to bench check a failed TRU at the depot

DLR - Depot labor rate

DCOND_i - TRUs condemned at the depot

DMH_i - Average manhours expended for corrective maintenance at the depot

DMC_i - Average supply and repair costs for lower level assemblies of a particular TRU

TABLE 3--Continued

DMR	- Depot consumable material consumption rate
UC_i	- TRU unit cost
PSC	- Average packing and shipping costs to CONUS locations
PSO	- Average packing and shipping costs to overseas locations
OS	- Fraction of total force deployed to overseas locations
W_i	- TRU weight in pounds

which have been removed from the ATE. The term

$$\frac{(TOH)(QPA_i)(1-RIP_i)}{MTBF_i}$$

refers to the failed items returned to the depot for repair. The cost to benchcheck each failed TRU is (DBCMH)(DLR) and the cost to repair the TRU that has not been condemned is

$$(1-DCOND_i) [(DMH_i)(DLR+DMR) + (DMC_i)(UC_i)]$$

where $(1-DCOND_i)$ is the fraction of TRUs not condemned at the depot, DMH is the manhours to repair the TRU, $(DLR+DMR)$ is the cost per manhour to repair the TRU including the cost of the base consumable material consumption rate (DMR), expressed in dollars per hour, and $(DMC_i)(UC_i)$ is the cost of stockage and repair of TRU subassemblies. The TRU transportation cost from the bases to the depot is divided into overseas (PSO) and CONUS (PSC) rates. The combined transportation rate is

$$(PSC)(1-OS) + (PSO)(OC),$$

where OS is the fraction of bases overseas. The one-way transportation cost would be

$$[(PSC)(1-OS) + (PSO)(OS)] (1.35W_i)$$

where $1.35 W_i$ is the package weight of each TRU. The total two-way transportation cost would be

$$2[(PSC)(1-OS) + (PSO)(OS)](1.35 W_i)$$

The off-equipment maintenance cost for n TRUs would then be

$$\begin{aligned} = & \sum_{i=1}^n \frac{(TOH)(QPA_i)(1-RIP_i)}{MTBF_i} \{ (DBCMH_i)(DLR) \\ & + (1-DCOND_i) \left[(DMH_i)(DLR+DMR) + (DMC_i)(UC_i) \right] \} \\ & + 2[(PSC)(1-OS) + (PSO)(OS)](1.35 W_i) \} \end{aligned}$$

Inventory Management (C_4). The inventory management cost equation includes all factors that can be attributed to new inventory life cycle costs based on the number of spares estimated to have been required. The computer equation and variable definitions are shown in Table 4. The cost to enter the N TRUs and items within the TRU into the government inventory is

$$[IMC + (PIUP)(RMC)] \sum_{i=1}^N (PP_i + 1)$$

where IMC is the initial management cost, $(PIUP)(RMC)$ is the recurring management cost over the life of the system, and PP is the number of new consumable items within a TRU.

TABLE 4

INVENTORY MANAGEMENT COST (C₄)

$$C_4 = [IMC + (PIUP)(RMC)] \sum_{i=1}^N (PP_i + 1) + (PIUP)(M)(SA)(N)$$

PP_i - Number of new "p" coded consumable items in a TRU

PIUP - Life of the system in years

RMC - Recurring management cost to maintain a line item of supply in the wholesale inventory system

IMC - Initial management cost to introduce a new line item of supply into the Air Force inventory

SA - Annual inventory management cost per line item

N - Number of different TRUs within the ATE

M - Number of bases

The base supply management cost for n TRUs over the life of the system at M number of bases is

$$(PIUP) (M) (SA) (N)$$

where SA is the annual base supply management cost per TRU. The total cost then for inventory management is

$$[IMC + (PIUP) (RMC)] \sum_{i=1}^N (PP_i + 1) + (PIUP) (M) (SA) (N)$$

Cost of Support Equipment (C_5). The complete equation and variable definitions for the cost of support equipment are shown in Table 5. Equation C_5 contains those variables which pertain to the cost of new peculiar items necessary to support the ATE. In order to compute the support equipment cost it is first necessary to determine the number of test equipment required. This is done using the queueing theory equation

$$n = \frac{\lambda}{\rho u}$$

where n = number of servers

λ = workload arrival rate

u = service rate of one server

ρ = combined utilization rate of one server

For this particular application, n is the number of pieces of support equipment which will be required to support the

TABLE 5
COST OF SUPPORT EQUIPMENT (C_5)

$$C_5 = \sum_{i=1}^N \frac{(\text{POH}) (\text{QPA}_i) (1 - \text{RIP}_i) [\text{DBCMH}_i + (1 - \text{DCOND}_i) (\text{DMH}_i)]}{\text{MTBF}_i}.$$

$$\sum_{j=1}^K \frac{[(1 + \text{PIUP}) (\text{COD}_j) (\text{CAD}_j)]}{(\text{DUR}_j) (\text{DAA}) (1 - \text{DOWN}_j)}$$

$$+ [1 + 0.1 (\text{PIUP})] [\text{DCA} + \text{DPA} + \text{M}(\text{BCA})]$$

POH - Peak operating hours per month

QPA_i - Quantity of like TRUs

RIP_i - Fraction of maintenance actions that can be repaired in place

MTBF_i - Mean time between failure

DBCMH_i - Depot bench check manhours

DCOND_i - Fraction of TRUs condemned at the depot

DMH_i - Average depot manhours expended in repair of TRU

TABLE 5--Continued

PIUP	- Operating life of system in years
COD_j	- Annual fraction of support equipment cost attributed to maintenance of the support equipment
CAD_j	- Depot support equipment unit cost
DUR_j	- Combined equipment utilization rate at the depot
DAA	- Manhours available per man at the depot
$DOWN_j$	- Fraction of time the support equipment is down for maintenance
DCA	- Total cost of additional items of common depot support equipment
DPA	- Total cost of additional items of peculiar depot support equipment
BCA	- Cost of additional items of common base shop support equipment per base
M	- Number of bases where ATE is located
K	- Number of line items of peculiar shop support equipment used in repair of the TRU

the depot workload. The depot workload arrival rate, λ , will be

$$\frac{(\text{POH}) (\text{QPA}_i) (1-\text{RIP}_i)}{\text{MTBF}_i}$$

where

$$\frac{(\text{POH}) (\text{QPA}_i)}{\text{MTBF}_i}$$

is the total number of failures and $(1-\text{RIP}_i)$ is the fraction of failures which cannot be repaired-in-place. The service rate, μ , will be

$$\frac{(\text{DAA}) (1-\text{DOWN}_j)}{[\text{DBCMH}_i + (1-\text{DCOND}_i) (\text{DMH}_i)]}$$

where DAA represents the manhours available per man at the depot, $(1-\text{DOWN}_j)$ is the fraction of time the j^{th} item of support equipment will be operational and

$$[\text{DBCMH}_i + (1-\text{DCOND}_i) (\text{DMH}_i)]$$

represents the manhours to benchcheck and repair the i^{th} TRU.

The combined utilization rate ρ of the support equipment is defined as DUR_j . Since

$$n = \frac{\lambda}{\rho \mu}$$

and substituting the support equipment variables, the following equation is obtained.

$$n = \frac{\frac{(POH) (QPA_i) (1-RIP_i)}{MTBF_i}}{(DUR_j) \left[\frac{(DAA) (1-DOWN_j)}{DBCMH_i + (1-DCOND_i) DMH_i} \right]}$$

Simplifying, the number of pieces of support equipment required becomes

$$n = \frac{(POH) (QPA_i) (1-RIP_i) [DBCMH_i + (1-DCOND_i) DMH_i]}{(DUR_j) (DAA) (MTBF_i) (1-DOWN_j)}$$

The cost of each item of support equipment will be designated CAD_j and the cost to maintain the support equipment over the life of the ATE will be defined as

$$(PIUP) (COD_j) (CAD_j),$$

where COD_j is the annual cost to maintain the support equipment (SE) expressed as a fraction of the unit cost (CAD_j). Therefore, the cost to procure and maintain the j^{th} item of SE will be

$$(CAD_j) + (PIUP) (COD_j) (CAD_j)$$

or $[1 + (PIUP) (COD_j)] (CAD_j)$

The cost of the j^{th} item of SE for the i^{th} TRU would then be

$$\frac{(POH)(QPA_i)(1-RIP_i)[DBCMH_i+(1-DCOND_i)(DMH_i)]}{(DUR_j)(DAA)(MTBF_i)(1-DOWN_j)} \cdot [1 + (PIUP)(COD_j)](CAD_j)$$

Included in the SE cost is the cost of additional items of common depot support equipment (DCA), cost of additional items of peculiar depot support equipment (DPA), cost of additional items of common base shop support equipment per base (BCA), and the cost to maintain the equipment over the life of the ATE (PIUP). It is assumed that the annual cost to maintain the equipment is 10 percent of this combined cost; therefore, the cost of the additional equipment is,

$$[DCA+DPA+M(BCA)] + 0.1 (PIUP)[DCA+DPA+M(BCA)]$$

where M is the number of bases.

If there are N number of TRUs and K number of pieces of support equipment required per each TRU, then the total cost of SE is

$$\sum_{i=1}^N \frac{(POH)(QPA_i)(1-RIP_i)[DBCMH_i+(1-DCOND_i)(DMH_i)]}{MTBF_i} \cdot \sum_{j=1}^K \frac{[(1+PIUP)(COD_j)(CAD_j)]}{(DUR_j)(DAA)(1-DOWN_j)} + [1+0.1(PIUP)][DCA+DPA+M(BCA)]$$

Cost of Personnel Training (C_6). The cost of personnel training as shown in Table 6, includes those factors which represent the total cost of training base and depot personnel over the life of the ATE.

The first step in determining the cost of training is to find the total number of personnel that would be required to support the system over its operating life. The total base corrective maintenance manhours expended over the life of the ATE is the number of failures over the life of the system

$$\frac{(\text{TOH}) (\text{QPA}_i)}{\text{MTBF}_i}$$

multiplied by the repair-in-place manhours:

$$[(\text{PAMH}_i) + (\text{RIP}_i) (\text{IMH}_i) + (1 - \text{RIP}_i) (\text{RMH}_i)]$$

as defined in development of equation C_2 , page 53. The preventive maintenance manhours would simply be:

$$\frac{\text{TOH}}{\text{SMI}} (\text{SMH})$$

Therefore, for N number of TRUs, the total base maintenance manhours are

$$\sum_{i=1}^n \frac{(\text{TOH}) (\text{QPA}_i)}{\text{MTBF}_i} [(\text{PAMH}_i) + (\text{RIP}_i) (\text{IMH}_i) + (1 - \text{RIP}_i) (\text{RMH}_i)]$$

$$+ \frac{\text{TOH}}{\text{SMI}} (\text{SMH})$$

TABLE 6
COST OF PERSONNEL TRAINING (C_6)

$$C_6 = \frac{[1 + (PIUP-1)(TRB)]}{(PIUP)(PMB)} (TCB) \left[\sum_{i=1}^N \frac{(TOH)(QPA_i)}{MTBF_i} \right] \{ PAMH_i + RIP_i(IMH_i) \} +$$

$$(1-RIP_i)(RMH_i) \left\{ + \frac{TOH(SMH)}{SMI} \right\} + \frac{[1 + (PIUP-1)(TRD)]}{(PIUP)(PMD)} TCD .$$

$$\sum_{i=1}^N \frac{(TOH)(QPA_i)(1-RIP_i)}{MTBF_i} [DBCMH_i + (1-DCOND_i)DMH_i] + TE$$

PIUP - Operating life in years of the system

TRB - Annual turnover rate for base personnel

TRD - Annual turnover rate for depot personnel

TCB - Cost of training per man at base level

TCD - Cost of training per man at depot level

PMB - Direct productive manhours per man per years at base

PMD - Direct productive manhours per man per year at depot

TABLE 6--Continued

TOH	- Total operating hours over the life of the system
QPA _i	- Quantity of like TRUs
MTBF _i	- Mean time between failure
PAMH _i	- Average preparation and access time expended
RIP _i	- Fraction of TRUs that can be repaired in place
IMH _i	- Average manhours expended for corrective action in place
RMH _i	- Average manhours expended for isolating, removing, and replacing a failed TRU
SMI	- Scheduled maintenance interval
SMH	- Average manhours expended per preventive maintenance action
DBCMMH _i	- Average manhours expended in depot bench check
DCOND _i	- Fraction of TRUs condemned at the depot
DMH _i	- Average manhours expended to correct failed TRU at the depot
TE	- Cost of training equipment

Similarly, the total depot maintenance manhours expended over the life of the ATE are

$$\sum_{i=1}^n \frac{(TOH) (QPA_i) (1-RIP_i)}{MTBF_i} [(DBCMH_i) + (1-DCOND_i) (DMH_i)]$$

(Refer to derivation of equation C₃.)

If PMB represents the base direct productive man-hours per man per year, PMD the depot direct productive manhours per man per year and PIUP the operating life of the system, then the number of personnel required annually to maintain the ATE is

$$\begin{aligned} & \sum_{i=1}^n \frac{(TOH) (QPA_i) [(PAMH_i) + (RIP_i) (IMH_i) + (1-RIP_i) (RMH_i)] + \frac{TOH}{SMI} (SMH)}{(MTBF_i) (PIUP) (PMB)} \\ & + \sum_{i=1}^n \frac{(TOH) (QPA_i) (1-RIP_i) [(DBCMH_i) + (1-DCOND_i) (DMH_i)]}{(MTBF_i) (PIUP) (PMD)} \end{aligned}$$

If TCB is the cost to train personnel at the base, TCD is the cost to train personnel at the depot, and TE is the cost of training equipment, then the total personnel training cost (assuming no personnel turnover) is:

$$\begin{aligned} & \frac{TCB}{(PIUP) (PMB)} \left[\sum_{i=1}^n \frac{(TOH) (QPA_i)}{MTBF_i} [(PAMH_i) + (RIP_i) (IMH_i) + (1-RIP_i) (RMH_i)] + \frac{TOH}{SMI} (SMH) \right] \\ & + \frac{TCD}{(PIUP) (PMD)} \left[\sum_{i=1}^n \frac{(TOH) (QPA_i) (1-RIP_i)}{MTBF_i} [(DBCMH_i) + (1-DCOND_i) (DMH_i)] \right] + TE \end{aligned}$$

However, as a result of personnel turnover, additional training costs will be incurred. If the annual turnover rate at the base is TRB and at the depot is TRD, then the turnover over the life of the system (not including the first year) is: $(PIUP-1)(TRB)$ and $(PIUP-1)(TRD)$, respectively. Thus the final expression for C_6 is:

$$\begin{aligned} & \frac{[1+(PIUP-1)(TRB)]}{(PIUP)(PMB)} TCB \left[\sum_{i=1}^n \frac{(TOH)(QPA_i)[(PAMH_i)+(RIP)_i(IMH_i)]}{MTBF_i} \right. \\ & \quad \left. + \frac{(1-RIP_i)(RMH_i)}{SMI} + \frac{TOH}{SMI} (SMH) \right] \\ & + \frac{[1+(PIUP-1)(TRD)]}{(PIUP)(PMD)} (TCD) \left[\sum_{i=1}^n \frac{(TOH)(QPA_i)(1-RIP_i)}{MTBF_i} \right. \\ & \quad \left. + \frac{[DBCMI_i+(1-DCOND_i)(DMH_i)]}{SMI} \right] + TE \end{aligned}$$

Cost of Management and Technical Data (C_7). The equation for the cost of management and technical data includes the labor costs associated with the preparation of maintenance forms and the costs of acquiring and maintaining necessary technical data. The complete equation and variable definitions are shown in Table 7. Every corrective maintenance action, whether on-equipment or

TABLE 7

COST OF MANAGEMENT AND TECHNICAL DATA (C_7)

$$C_7 = \sum_{i=1}^N \frac{(\text{TOH})(\text{QPA}_i)}{\text{MTBF}_i} [\text{MRO} + (1 - \text{RIP}_i)(\text{SR} + \text{TR} + \text{MRF})] \text{BLR}$$

$$+ \frac{\text{TOH}}{\text{SMI}} [\text{MRO} + 0.1 (\text{SR} + \text{TR})] \text{BLR} + \text{TD}(\text{JJ} + \text{H})$$

TOH - Total operating hours of the system

QPA_i - Quantity of like items per system

MTBF_i - Mean time between failure

MRO - Average manhours per failure to complete on-equipment maintenance records

MRF - Average manhours per failure to complete off-equipment maintenance records

RIP_i - Fraction of failures that can be repaired in place

BLR - Base labor rate

SR - Average manhours per failure to complete supply transaction records

TR - Average manhours per failure to complete transportation forms

TD - Average cost per original page of technical documentation

TABLE 7--Continued

JJ - Number of pages of organizational level technical orders to maintain the system

SMI - Scheduled maintenance interval

H - Number of pages of depot level technical orders required to maintain the system

off-equipment, requires completion of maintenance records. In the case of off-equipment failure, supply transaction records and transportation forms have to be completed. If total number of failures over the life of the ATE is

$$\frac{(TOH) (QPA_i)}{MTBF_i}$$

then the total manhours expended per failure is

$$[MRO + (1-RIP_i) (SR+TR+MRF)].$$

MRO represents average manhours per failure to complete the on-equipment maintenance records, MRF represents average manhours to complete the off-equipment maintenance records, SR represents average manhours per failure to complete the supply transaction records and TR represents average manhours per failure to complete the transportation records. The fraction of off-equipment maintenance action is $(1-RIP_i)$. The cost for completion of the maintenance and supply records and the transportation forms for N number of TRUs is:

$$\sum_{i=1}^n \frac{(TOH) (QPA_i)}{MTBF_i} [MRO + (1-RIP_i) (SR+TR+MRF)] BLR$$

where BLR is the base labor rate.

The preventive maintenance actions also result in manhours expended in record keeping. The total number of

preventive maintenance actions over the life of the system is

$$\frac{TOH}{SMI}$$

and the average manhours per action to complete the on-equipment maintenance records is MRO. If the percentage of the preventive maintenance time associated with the completion of maintenance and supply forms is 10 percent, then the manhours are $0.1 (SR+TR)$, and the total cost for completing forms as a result of preventive maintenance actions is

$$\frac{TOH}{SMI} [MRO + 0.1 (SR+TR)] BLR$$

The technical data cost is the cost of maintaining the organizational and depot level technical orders. The average cost to maintain a page of either the organizational or the depot level technical orders is TD. If the number of pages of the organizational level technical orders is JJ and the number of pages of the depot level technical orders is H, then the total cost of maintaining the technical orders is

$$TD (JJ+H)$$

The total cost of management and technical data is then,

$$\sum_{i=1}^n \frac{(TOH) (QPA_i)}{MTBF_i} [MRO + (1 - RIP_i) (SR + TR + MRF)] BLR \\ + \frac{TOH}{SMI} [MRO + 0.1 (SR + TR)] BLR + TD (JJ + H)$$

Calibration Requirements Cost (C_8). This equation was derived using dimensional analysis (12). The equation is shown in Table 8.

For the purpose of the equation derivation calibration occurs at two levels, system level and TRU level. Calibration cost is the sum of the costs at the two calibration levels.

The system level variables and their basic units are as follows:

1. LIFE (days)
2. SCI (days/calibration)
3. SCMH (MH/calibration)
4. CIVLR (\$/MH)
5. C (\$)

where: LIFE is the operational service life of the ATE in days; SCI is the calibration interval in days per calibration; SCMH is the manhours per calibration; CIVLR is the labor rate for calibration at Class IV calibration shop, in dollars per manhour; and C is the cost for calibration

TABLE 8

CALIBRATION REQUIREMENTS (C₈)

$$C_8 = \sum_{i=1}^{NSYS} \left\{ \frac{365 (PIUP) (SMH_i) (CIVLR)}{(SCI_i)} + \sum_{j=1}^N \frac{365 (PIUP) (OPA_{ij})}{(TRUCI_{ij})} \right\} \{ (TRUCMH_{ij}) [(CI) (CILR)] \\ + (CII) (CILR) + (CIV) (CIVLR)] + (CARF) [(CI) (CILR) (FICR) + (CII) (CILR) (FIICR) \\ + (CIV) (CIVLR) (FIVCR)] \}$$

N - Number of different TRUs within the systems, within the ATE

NSYS - Number of systems within the ATE

PIUP - Operational service life of the ATE in years

SCI_i - Scheduled calibration interval for the system

SCMH_i - Manhours to perform calibration on the system

TRUCI_{ij} - Calibration interval for a TRU

TRUCMH_{ij} - Manhours to calibrate a TRU

CI - Factor which is 0 if no calibration at Class I lab is required or 1 if calibration at Class I lab is required

TABLE 8--Continued

CII	- Factor which is 0 if no calibration at Class II lab is required or 1 if calibration at Class II lab is required
CIV	- Factor which is 0 if no calibration at class IV lab is required or 1 if calibration at Class IV lab is required
CILR	- Labor rate at a Class I lab
CIILR	- Labor rate at a Class II lab
CIVLR	- Labor rate at a Class IV lab
FICR	- Manhours spent on repair of items to be calibrated at Class I lab
FIICR	- Manhours spent on repair of items to be calibrated at Class II lab
FIVCR	- Manhours spent on repair of items to be calibrated at Class IV lab
QPA _i	- Quantity of like TRUs
CARF	- Fraction of units (calibrated) requiring repair

in dollars. LIFE and SCI take into account that calibration is accomplished on a calendar-time basis.

Since there are five variables and four basic units, there is one dimensionless Pi term, and

$$\Pi_1 = K^1 = (\text{LIFE})^a (\text{SCI})^b (\text{SCMH})^c (\text{CIVLR})^d (C)^e \quad (1)$$

or:

$$\Pi_1 = K^1 = (\text{DAYS})^a \left(\frac{\text{DAYS}}{\text{CAL}}\right)^b \left(\frac{\text{MH}}{\text{CAL}}\right)^c \left(\frac{\$}{\text{MH}}\right)^d (\$)^e \quad (2)$$

Since the result is a dimensionless product, then,

$$\begin{aligned} (\text{DAYS})^0 (\text{CAL})^0 (\text{MH})^0 (\$)^0 &= (\text{DAYS})^a (\text{DAYS})^b (\text{CAL})^{-b} \\ &(\text{MH})^c (\text{CAL})^{-c} (\$)^d (\text{MH})^{-d} (\$)^e \end{aligned}$$

Then:

$$\begin{aligned} 0 &= a + b && \text{for DAYS} \\ 0 &= -b - c && \text{for CAL} \\ 0 &= c - d && \text{for MH} \\ 0 &= d + e && \text{for \$} \end{aligned}$$

To solve these four equations with five unknowns, let $a = 1$

Then:

$$b = -1; c = 1; d = 1; e = -1$$

Substitution in (1) yields

$$K^1 = (\text{LIFE})^1 (\text{SCI})^{-1} (\text{SCMH})^1 (\text{CIVLR})^1 (C)^{-1}$$

solving for C

$$C = K(\text{LIFE})(\text{SCMH})(\text{CIVLR})/(\text{SCI}), K=1/k^1$$

or $C_{81} = (\text{LIFE})(\text{SCMH})(\text{CIVLR})/(\text{SCI}), K=1$

The TRU calibration level variables and their basic units are as follows:

1. LIFE (days)
2. TRUCI (days/calibration)
3. TRUCMH (MH/calibration)
4. CILR (\$/MH)
5. CIILR (\$/MH)
6. CIVLR (\$/MH)
7. CARF (repair/calibration)
8. FICR (MH/repair)
9. FIICR (MH/repair)
10. FIVCR (MH/repair)
11. C (\$)

where: LIFE is the operational service life of the ATE in days; TRUCI is the TRU calibration interval in days; TRUCMH is the manhours per calibration; CILR, CIILR, and CIVLR are the labor rates for calibration at Class I, II, and IV calibration shop respectively, in dollars; CARF is the proportion of repairs per calibration; FICR, FIICR, and FIVCR are the manhours per repair at Class I, II and IV calibration shop respectively; and C is the cost for calibration

in dollars. Calibration is accomplished on a calendar-time basis.

Since there are 11 variables and 5 basic units, there are 6 dimensionless Pi terms, and

$$\Pi = (\text{LIFE})^a (\text{TRUCI})^b (\text{TRUCMH})^c (\text{CILR})^d (\text{CIILR})^e (\text{CIVLR})^f \\ (\text{CARF})^g (\text{FICR})^h (\text{FIICR})^i (\text{FIVCR})^j (\text{C})^k \quad (3)$$

or:

$$\Pi = (\text{DAYS})^a \left(\frac{\text{DAYS}}{\text{CAL}}\right)^b \left(\frac{\text{MH}}{\text{CAL}}\right)^c \left(\frac{\$}{\text{MH}}\right)^d \left(\frac{\$}{\text{MH}}\right)^e \left(\frac{\$}{\text{MH}}\right)^f \left(\frac{\text{REP}}{\text{CAL}}\right)^g \\ \left(\frac{\text{MH}}{\text{REP}}\right)^h \left(\frac{\text{MH}}{\text{REP}}\right)^i \left(\frac{\text{MH}}{\text{REP}}\right)^j (\$)^k \quad (4)$$

Since the result is a dimensionless product, then:

$$(\text{DAYS})^0 (\text{CAL})^0 (\text{MH})^0 (\$)^0 (\text{REP})^0 = (\text{DAYS})^a (\text{DAYS})^b (\text{CAL})^{-b} \\ (\text{MH})^c (\text{CAL})^{-c} (\$)^d (\text{MH})^{-d} (\$)^e (\text{MH})^{-e} (\$)^f (\text{MH})^{-f} \\ (\text{REP})^g (\text{CAL})^{-g} (\text{MH})^h (\text{REP})^{-h} (\text{MH})^i (\text{REP})^{-i} \\ (\text{MH})^j (\text{REP})^{-j} (\$)^k$$

Then

$$\begin{array}{ll} 0 = a + b & \text{for DAYS} \\ 0 = -b - c - g & \text{for CAL} \\ 0 = c - d - e - f + h + i + j & \text{for MH} \\ 0 = d + e + f + k & \text{for \$} \\ 0 = g - h - i - j & \text{for REP} \end{array}$$

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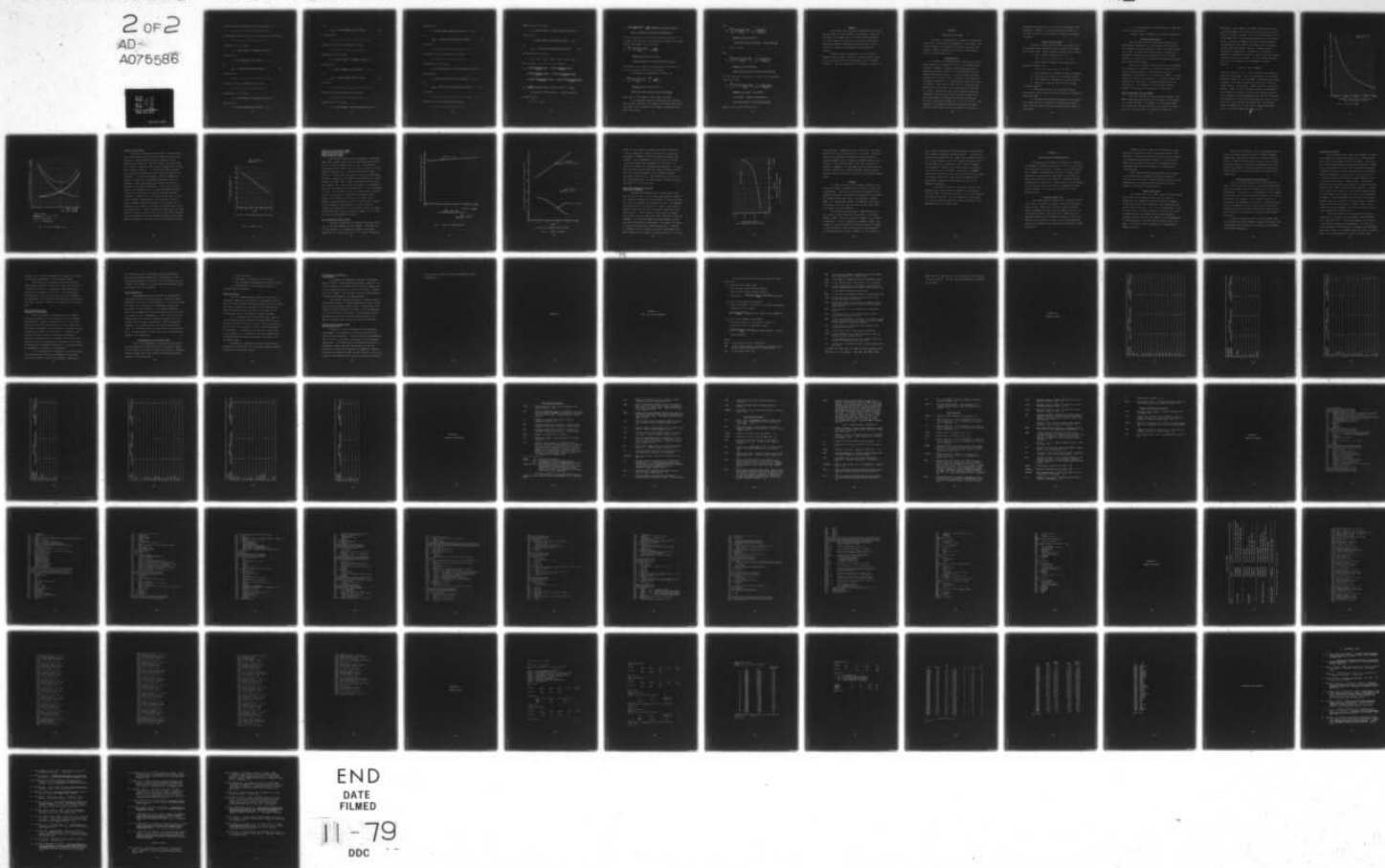
AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL--ETC F/G 14/1
AN OPERATING AND SUPPORT COST MODEL FOR AVIONICS AUTOMATIC TEST--ETC(U)
SEP 79 J A GUERRA , A J LESKO , J G PEREIRA
AFIT-LSSR-21-79B

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To solve these five equations with 11 unknowns, let

$$h = 0; i = 0; j = 0; e = 0; f = 0; a = 1$$

Simultaneous solution of the five equations will then yield

$$b = -1; c = 1, d = 1; k = -1, g = 0$$

Substitution in (3) gives

$$\Pi_1 = (\text{LIFE})^1 (\text{TRUCI})^{-1} (\text{TRUCMH})^1 (\text{CILR})^1 (\text{C})^{-1}$$

Solving for C

$$C = (\text{LIFE}) (\text{TRUCMH}) (\text{CILR}) / (\text{TRUCI}), \quad \Pi_1 = 1$$

or:

$$C_{821} = (\text{LIFE}) (\text{TRUCMH}) (\text{CILR}) / (\text{TRUCI}) \quad (5)$$

If we now let

$$h = 0, i = 0, j = 0, d = 0, f = 0, a = 1,$$

solution of the five equations will yield

$$b = -1; c = 1; e = 1; k = -1; g = 0$$

Substitution in (3) gives

$$\Pi_2 = (\text{LIFE})^1 (\text{TRUCI})^{-1} (\text{TRUCMH})^1 (\text{CIILR})^1 (\text{C})^{-1}$$

Solving for C

$$C = (\text{LIFE}) (\text{TRUCMH}) (\text{CIILR}) / (\text{TRUCI}), \quad \Pi_2 = 1$$

or:

$$C_{822} = (\text{LIFE}) (\text{TRUCMH}) (\text{CIILR}) / (\text{TRUCI}) \quad (6)$$

If we now let

$$h = 0; i = 0; j = 0; d = 0; e = 0; a = 1,$$

solution of the five equations will yield

$$b = -1; c = 1; f = 1; k = -1; g = 0$$

Substitution in (3) gives

$$\Pi_3 = (\text{LIFE})^1 (\text{TRUCI})^{-1} (\text{TRUCMH})^1 (\text{CIVLR})^1 (C)^{-1}$$

Solving for C

$$C = (\text{LIFE}) (\text{TRUCMH}) (\text{CIVLR}) / (\text{TRUCI}), \quad \Pi_3 = 1$$

or:

$$C_{823} = (\text{LIFE}) (\text{TRUCMH}) (\text{CIVLR}) / (\text{TRUCI}) \quad (7)$$

If we let

$$c = 0; e = 0; f = 0; i = 0; j = 0; a = 1,$$

solution of the five equations will yield

$$b = -1; g = 1; d = 1; k = -1; h = 1$$

Substitution in (3) gives

$$\Pi_4 = (\text{LIFE})^1 (\text{TRUCI})^{-1} (\text{CILR})^1 (\text{CARF})^1 (\text{FICR})^1 (C)^{-1}$$

Solving for C

$$C = (\text{LIFE}) (\text{CILR}) (\text{CARF}) (\text{FICR}) / (\text{TRUCI}), \quad \Pi_4 = 1$$

or:

$$C_{824} = (\text{LIFE}) (\text{CILR}) (\text{CARF}) (\text{FICR}) / (\text{TRUCI}) \quad (8)$$

If we let

$$c = 0; d = 0; f = 0; h = 0; j = 0; a = 1,$$

solution of the five equations will yield

$$b = -1; g = 1; e = 1; k = -1; i = 1$$

Substitution in (3) gives

$$\Pi_5 = (\text{LIFE})^1 (\text{TRUCI})^{-1} (\text{CIILR})^1 (\text{CARF})^1 (\text{FIICR})^1 (C)^{-1}$$

Solving for C

$$C = (\text{LIFE}) (\text{CIILR}) (\text{CARF}) (\text{FIICR}) / (\text{TRUCI}), \quad \Pi_5 = 1$$

or:

$$C_{825} = (\text{LIFE}) (\text{CIILR}) (\text{CARF}) (\text{FIICR}) / (\text{TRUCI}) \quad (9)$$

If we let

$$c = 0; d = 0; e = 0; h = 0; i = 0; a = 1,$$

solution of the five equations will yield

$$b = -1; g = 1; f = 1; k = -1; j = 1$$

Substitution in (3) gives

$$\Pi_6 = (\text{LIFE})^1 (\text{TRUCI})^{-1} (\text{CIVLR})^1 (\text{CARF})^1 (\text{FIVCR})^1 (\text{C})^{-1}$$

Solving for C

$$C = (\text{LIFE}) (\text{CIVLR}) (\text{CARF}) (\text{FIVCR}) / (\text{TRUCI}), \quad \Pi_6 = 1$$

or:

$$C_{826} = (\text{LIFE}) (\text{CIVLR}) (\text{CARF}) (\text{FIVCR}) / (\text{TRUCI}) \quad (10)$$

By experience we can write

$$C_{82} = C_{821} + C_{822} + C_{823} + C_{824} + C_{825} + C_{826}$$

Then, from (5), (6), (7), (8), (9), and (10)

$$\begin{aligned} C_{82} = & \frac{(\text{LIFE}) (\text{TRUCMH}) (\text{CILR})}{(\text{TRUCI})} + \frac{(\text{LIFE}) (\text{TRUCMH}) (\text{CIILR})}{(\text{TRUCI})} \\ & + \frac{(\text{LIFE}) (\text{TRUCMH}) (\text{CIVLR})}{(\text{TRUCI})} + \frac{(\text{LIFE}) (\text{CILR}) (\text{CARF}) (\text{FICR})}{(\text{TRUCI})} \\ & + \frac{(\text{LIFE}) (\text{CIILR}) (\text{CARF}) (\text{FIICR})}{(\text{TRUCI})} + \frac{(\text{LIFE}) (\text{CIVLR}) (\text{CARF}) (\text{FIVCR})}{(\text{TRUCI})} \end{aligned}$$

$$\begin{aligned} C_{82} = & \frac{\text{LIFE}}{\text{TRUCI}} \left\{ (\text{TRUCMH}) [(\text{CILR}) + (\text{CIILR}) + (\text{CIVLR})] + (\text{CARF}) \right. \\ & \left. [(\text{CILR}) (\text{FICR}) + (\text{CIILR}) (\text{FIICR}) + (\text{CIVLR}) (\text{FIVCR})] \right\} \end{aligned}$$

As stated above,

$$C_8 = C_{81} + C_{82}$$

$$C_8 = \frac{(LIFE) (SCMH) (CIVLR)}{SCI} + \frac{LIFE}{TRUCI} \left\{ (TRUCMH) [(CILR) + (CIILR) + (CIVLR)] + \right. \\ \left. (CARF) [(CILR) (FICR) + (CIILR) (FIICR) + (CIVLR) (FIVCR)] \right\}$$

Then above equation C_8 holds for one system and one TRU. If we take into account all systems within the ATE and all TRUs within the systems, the C_8 would be

$$C_8 = \sum_{i=1}^{NSYS} \frac{(LIFE) (SCMH_i) (CIVLR)}{(SCI_i)} + \sum_{j=1}^L \frac{LIFE}{(TRUCI_j)} \\ \left\{ (TRUCMH_j) [(CILR) + (CIILR) + (CIVLR)] + \right. \\ \left. (CARF) [(CILR) (FICR) + (CIILR) (FIICR) + (CIVLR) (FIVCR)] \right\}$$

where NSYS is the number of systems within an ATE and L is the total number of TRUs for all systems.

If the TRUs are aggregated by system, then

$$C_8 = \sum_{i=1}^{NSYS} \frac{(LIFE) (SMH_i) (CIVLR)}{(SCI_i)} + \sum_{j=1}^{NTRU} \frac{LIFE}{(TRUCI_{ij})} \\ \left\{ (TRUCMH_{ij}) [(CILR) + (CIILR) + (CIVLR)] + \right. \\ \left. (CARF) [(CILR) (FICR) + (CIILR) (FIICR) + (CIVLR) (FIVCR)] \right\}$$

where NTRU is the number of TRUs within a system.

If we consider that the system might have identical TRUs and QPA represents the number of identical TRUs within the system, and N represents the number of different TRUs within the system,

Then,

$$C_8 = \sum_{i=1}^{NSYS} \left\{ \frac{(LIFE) (SMH_i) (CIVLR)}{(SCI_i)} + \sum_{j=1}^N \frac{(LIFE) (OPA_{ij})}{(TRUCI_{ij})} \right. \\ \left. \{ (TRUCMH_{ij}) (CILR + CIILR + CIVLR) + \right. \\ \left. CARF [(CILR) (FICR) + (CIILR) (FIICR) + (CIVLR) (FIVCR)] \} \right\}$$

If LIFE = 365 PIUP

Then,

$$C_8 = \sum_{i=1}^{NSYS} \left\{ \frac{365 (PIUP) (SMH_i) (CIVLR)}{(SCI_i)} + \sum_{j=1}^N \frac{365 (PIUP) (OPA_{ij})}{(TRUCI_{ij})} \right. \\ \left. \{ (TRUCMH_{ij}) (CILR + CIILR + CIVLR) + \right. \\ \left. CARF [(CILR) (FICR) + (CIILR) (FIICR) + (CIVLR) (FIVCR)] \} \right\}$$

If a TRU goes for calibration to a particular calibration level only, then,

$$C_8 = \sum_{i=1}^{NSYS} \left\{ \frac{365 (PIUP) (SMH_i) (CIVLR)}{(SCI_i)} + \sum_{j=1}^N \frac{365 (PIUP) (OPA_{ij})}{(TRUCI_{ij})} \right. \\ \left. \{ (TRUCMH_{ij}) [(CI) (CILR) + (CII) (CIILR) + \right. \\ \left. (CIV) (CIVLR)] + (CARF) [(CI) (CILR) (FICR) + \right. \\ \left. (CII) (CIILR) (FIICR) + (CIV) (CIVLR) (FIVCR)] \} \right\}$$

where CI, CII, and CIV can be 0 or 1.

Summary

This chapter has provided an explanation of how the O&S Cost Model for ATE (OSCAT) was developed. Basically, the model is an adaptation of the AFLC Logistics Support Cost (LSC) model, with special provisions for ATE, and an additional equation representing ATE calibration costs. This latter equation was developed using dimensional analysis.

OSCAT has been programmed to run on the AFLC CREATE computer system. Chapter V discusses various sensitivity analyses that were accomplished using the OSCAT program. A copy of the program is contained in Appendix D.

CHAPTER V

ANALYSIS OF THE MODEL

Any model is valid only for a specific purpose and only within a certain set of parameters. This chapter contains a summary of the sensitivity analysis that was performed in order to establish guidelines for the model's potential future application.

Computer Model

In order to perform sensitivity analysis on the proposed Operation and Support Cost Model for Automatic Test Equipment (OSCATE), a computer program was developed by modifying applicable portions of the AFALD/XRSC Logistics Support Cost Model Version 1.1 (10) and by adding programming which was unique to ATE. A listing of the program is contained in Appendix D. A representative data base, shown in Appendix E, was created using the F-15 Avionics Intermediate Shop (AIS) depot and base maintenance information as a guide. The data for some of the variables were not immediately available and values assigned to these variables were based on estimates obtained from discussions with field and depot personnel (3; 4; 11; 16; 18; 22). Consequently, the results obtained by exercising the model using this data should not be construed as the actual

operating and support cost of the F-15 AIS Automatic Test Equipment. However, the data did provide the means to test the sensitivity of the model to changes in different variables.

Output from the Model

In order to facilitate analysis, the output from the computer model contains several different cost components of O&S costs. These components include the following:

1. Total logistics support cost; i.e.,
 $(C_1 + C_2 + C_3 + C_4 + C_5 + C_6 + C_7 + C_8)$.
2. Total logistics support cost broken out by specific category; i.e.,
 $(C_1, C_2, C_3, C_4, C_5, C_6, C_7, \text{ or } C_8)$.
3. Cost breakout of a specific system by category.
4. Cost ranking of TRUs for a particular system.
5. Cost breakout by category for a particular TRU.
6. Analysis of types and quantities of support equipment required.
7. TRU spares analysis to include the system availability, TRU availability and quantities, and expected backorders (XBO).
8. Maintenance generation analysis which includes the maintenance actions generated during peak operating hours (POH) and during the total operating hours (TOH) of the system.

9. A cross-reference of the TRU work unit code and the noun identification.

A sample output of OSCATE is contained in Appendix F.

Sensitivity Analysis

The variables that were selected for sensitivity analysis were those which, in the opinion of the authors, the contractor has some degree of control over during design of the ATE. By using the proposed model to analyze the variables to which Logistic Support Cost (LSC) is most sensitive, a contractor could improve equipment LSC through appropriate design changes.

Many of the trade-off analyses possible using OSCATE are suggested by the sensitivity analysis accomplished during this research effort. The following areas were addressed in this analysis: (1) reliability (MTBF), (2) maintainability (maintenance manhours), (3) repair concept (condemnation rate and repair in place percentage), and (4) availability. The remainder of this chapter discusses results of the sensitivity analysis in these areas.

Mean Time Between Failure (MTBF)

The first variable that was analyzed was MTBF. The MTBF of each TRU was varied from 100 percent to 500 percent of its baseline MTBF. For example, if the baseline MTBF for a particular TRU was 1000 hours, its value at 200 percent was 2000 hours and at 300 percent its MTBF was

3000 hours. This change in TRU MTBF resulted in the total logistics support cost ranging from \$15.93 million to \$5.4 million. A graph, Figure 2, of total logistic support cost versus MTBF shows the relationship over the entire range of values. As one might expect, the total logistics support cost decreases as the MTBF is increased; this is assuming the TRU unit cost remains constant. However, such an assumption is unrealistic. The TRU unit cost can be expected to increase as actions are taken to increase system reliability and, in turn, MTBF. The relationship between TRU unit cost and MTBF can be expressed as follows (20:421):

$$\text{TRU Unit Cost} = c(\text{MTBF})^a$$

where the values of c and a can be derived using historical data for like systems. Using this expression for the relationship between unit cost and MTBF, the designer can effect tradeoffs in his design regarding minimum total logistics support costs. A theoretical tradeoff analysis is shown in Figure 3, where the total logistics support cost decreases as the MTBF is increased and the total logistics support cost increases as the corresponding TRU unit cost increases. The combination of these two cost curves will result in the total cost curve shown by the dotted line. The optimum values for MTBF and unit cost can be obtained from that point on the curve where the slope is zero.

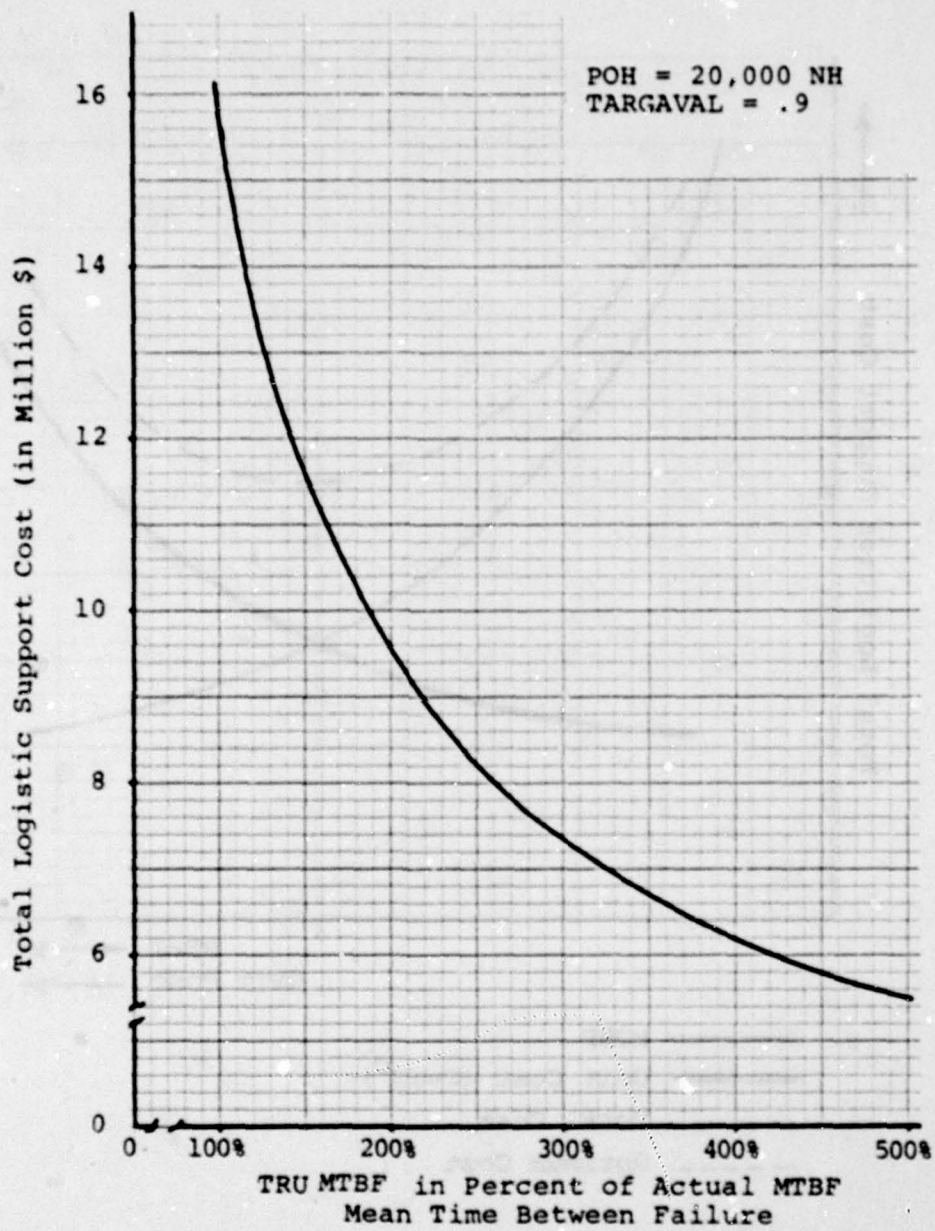


Fig. 2. TLSC vs. MTBF

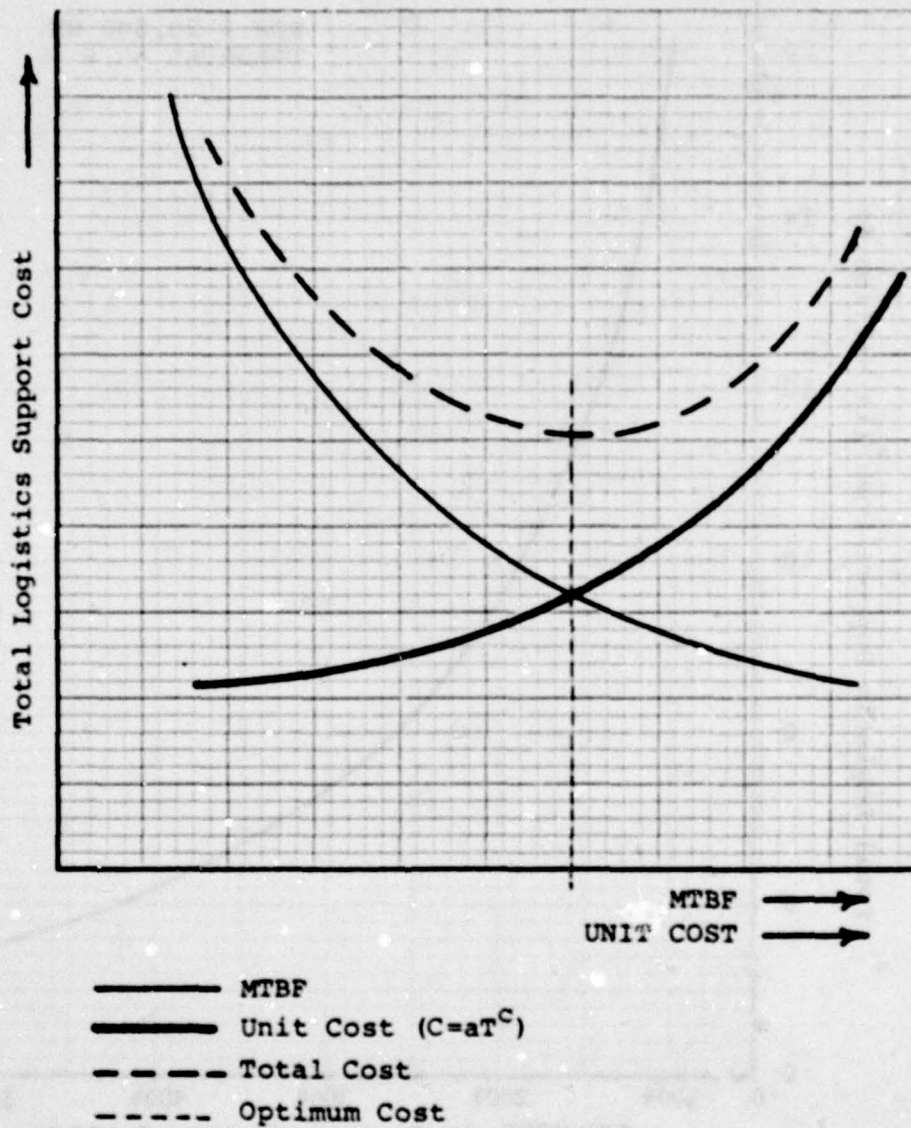


Fig. 3. TLSC vs. MTBF and UC

Repair in Place (RIP)

The next variable analyzed was RIP. This variable was chosen because the contractor has some latitude in the selection of components which can be repaired without removing the failed TRU. The RIP variable was varied from 0.1 to 0.65. A graph of total logistics support cost versus RIP is shown in Figure 4. It can be seen from the graph that as RIP was increased the total logistics support cost decreased. If RIP was increased it would be expected to cause an increase in on-equipment maintenance costs, a decrease in the off-equipment maintenance costs, and a decrease in TRU spares requirement. This result would be based on the assumption that a constant TRU MTBF was maintained as the fraction of in-place maintenance actions increased. Realistically, the higher the RIP value is, the lower the MTBF. Consequently, the designer will have to make a tradeoff between increasing his maintainability or decreasing his reliability in order to minimize total logistics support cost. Other considerations must enter into this decision, such as the skill level of the technicians performing the maintenance, and the possible addition of extra base support equipment to facilitate the RIP maintenance actions.

POH = 20,000
TARGAVAL = .90

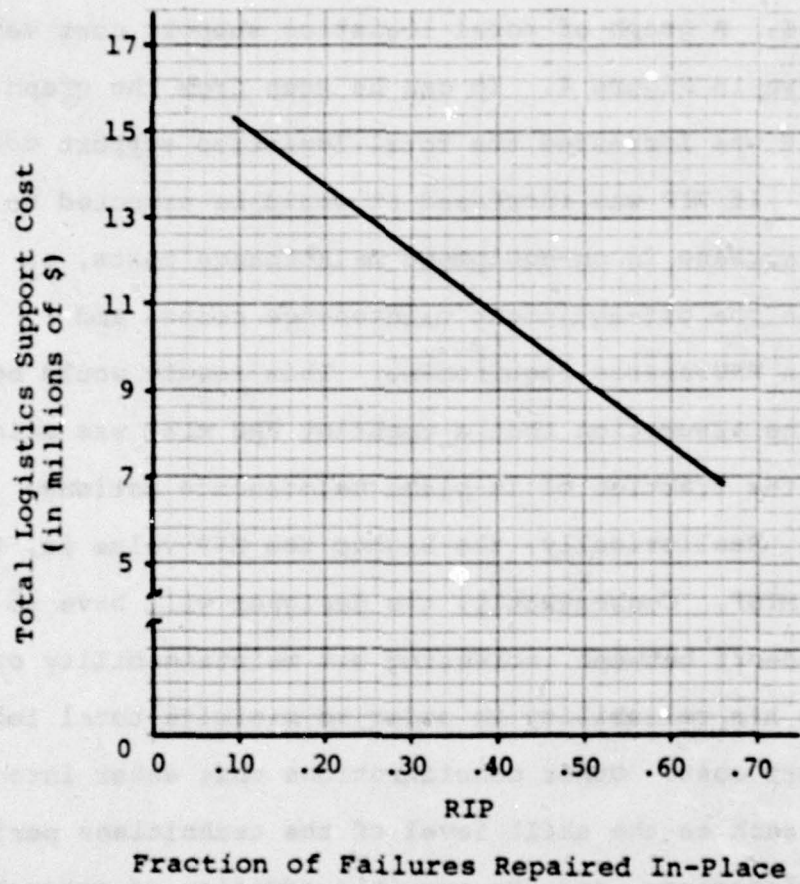


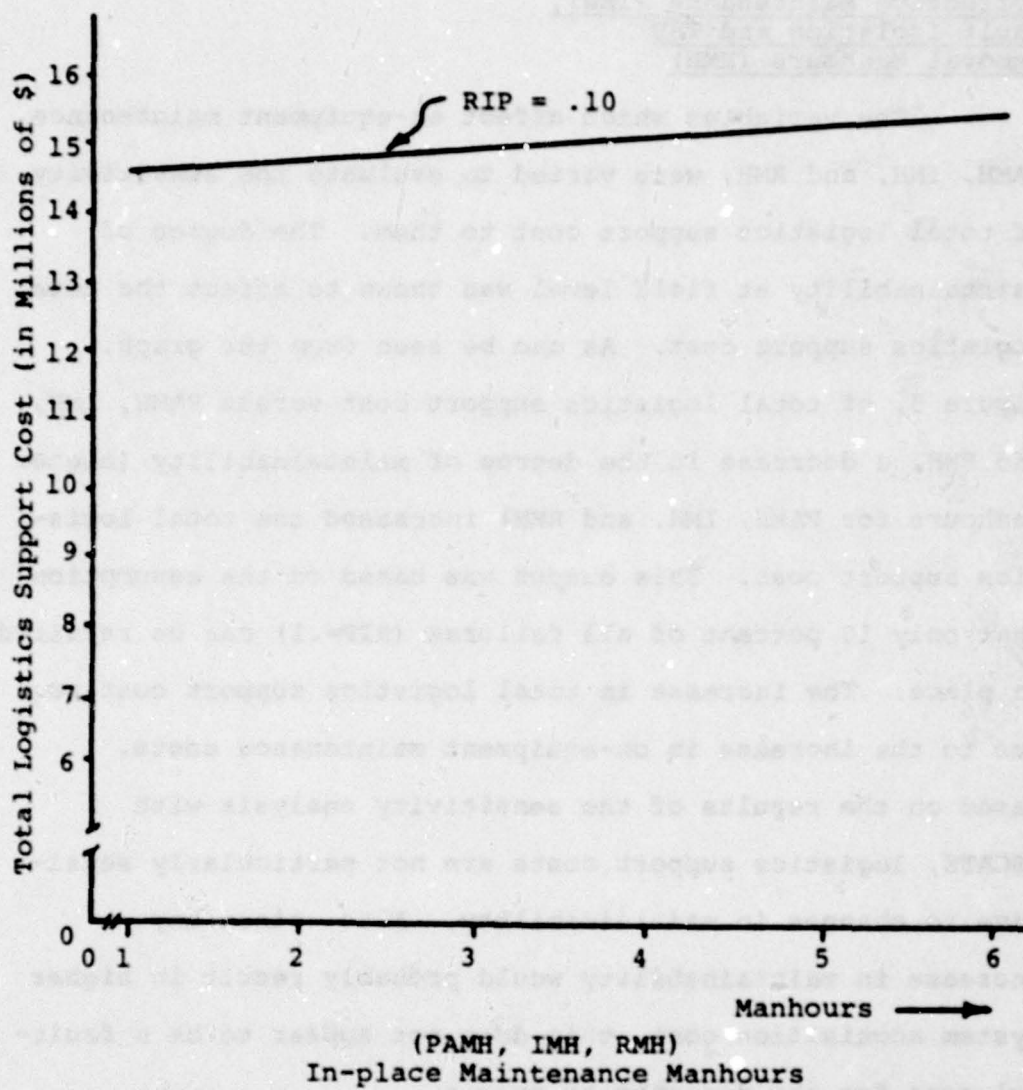
Fig. 4. TLSC vs. RIP

Preparation and Access (PAMH),
Corrective Maintenance (IMH),
Fault Isolation and TRU
Removal Manhours (RMH)

The variables which affect on-equipment maintenance, PAMH, IMH, and RMH, were varied to evaluate the sensitivity of total logistics support cost to them. The degree of maintainability at field level was shown to affect the total logistics support cost. As can be seen from the graph, Figure 5, of total logistics support cost versus PAMH, IMH, and RMH, a decrease in the degree of maintainability (higher manhours for PAMH, IMH, and RMH) increased the total logistics support cost. This output was based on the assumption that only 10 percent of all failures ($RIP=.1$) can be repaired in place. The increase in total logistics support cost was due to the increase in on-equipment maintenance costs. Based on the results of the sensitivity analysis with OSCATE, logistics support costs are not particularly sensitive to changes in maintainability. Also, since any increase in maintainability would probably result in higher system acquisition cost, this does not appear to be a fruitful area for the designer to pursue.

TRU Condemnation Rate (DCOND)

Another variable that the designer has some control over is the TRU condemnation rate (DCOND). The DCOND for the TRU depends on the component selection philosophy. DCOND was first varied from .05 to .8. Figure 6 shows the



POH = 20,000
TARGAVAL = .90

Fig. 5. TLSC vs. PAMH IMH RMH

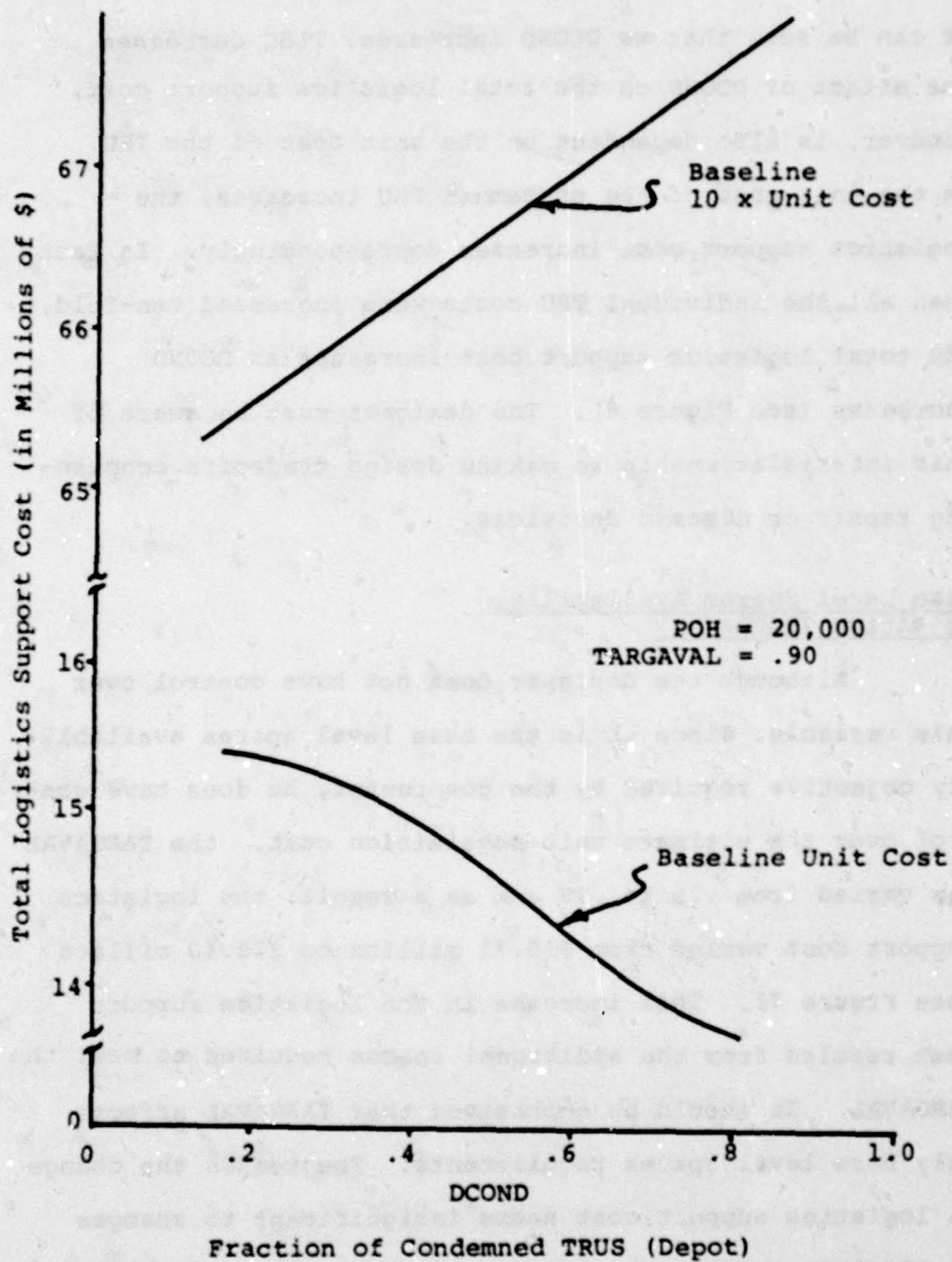
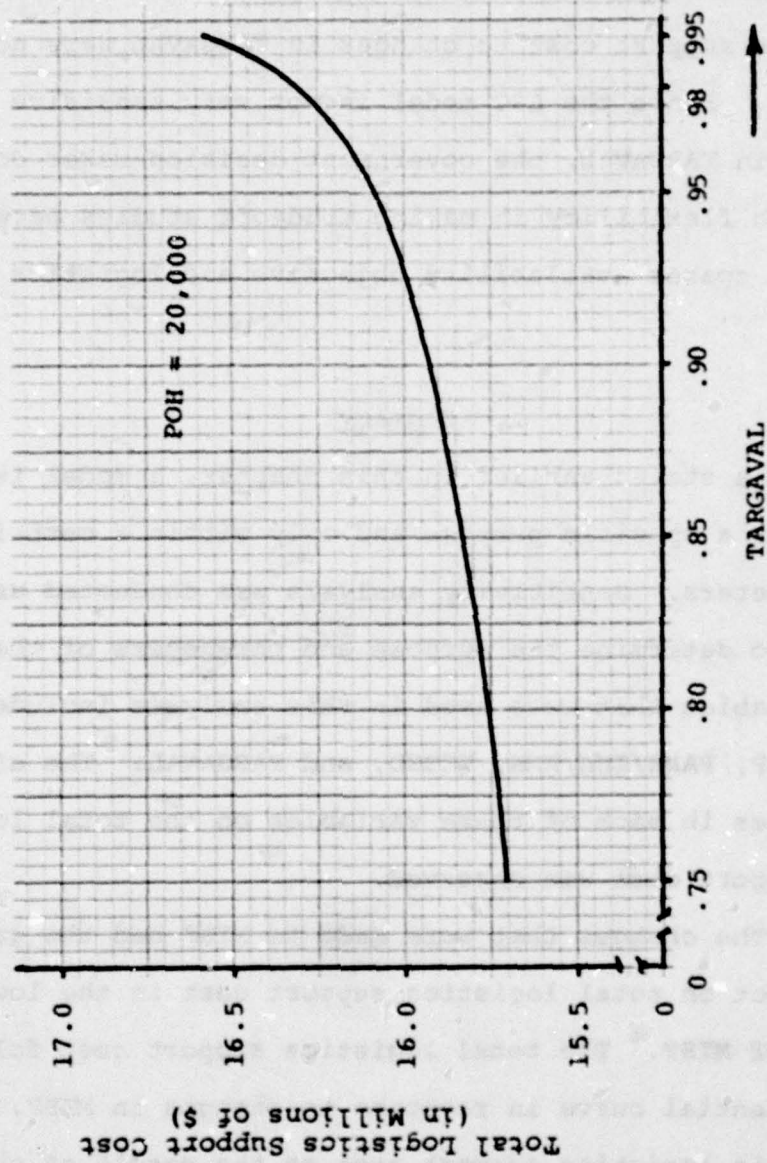


Fig. 6. TLSC vs. DCOND

graph of total logistics support cost versus DCOND rate. It can be seen that as DCOND increases, TLSC decreases. The effect of DCOND on the total logistics support cost, however, is also dependent on the unit cost of the TRU. As the unit cost of the condemned TRU increases, the logistics support cost increases correspondingly. In fact, when all the individual TRU costs were increased ten-fold, the total logistics support cost increases as DCOND increases (see Figure 6). The designer must be aware of this interrelationship in making design tradeoffs concerning repair or discard decisions.

Base Level Spares Availability
Objective (TARGAVAL)

Although the designer does not have control over this variable, since it is the base level spares availability objective required by the government, he does have control over the ultimate unit acquisition cost. the TARGAVAL was varied from .75 to .99 and as a result, the logistics support cost varied from \$15.71 million to \$16.40 million (see Figure 7). This increase in the logistics support cost results from the additional spares required to meet the TARGAVAL. It should be emphasized that TARGAVAL affects only base level spares requirements. The reason the change in logistics support cost seems insignificant to changes in TARGAVAL is that the base stock level requirements are small compared to the number of spares required to fill the



System Target Availability

Fig. 7. TLSC vs. TARGAVAL

depot pipeline. TARGAVAL was again varied, but this time the TRU unit cost was increased by 100 percent. Logistics support cost increased significantly but the change in logistics support cost to changes in TARGAVAL were not significant. Since the LSC model is not very sensitive to changes in TARGAVAL, the government decision-maker does not have much flexibility in making tradeoff studies between the base spares availability objective and logistics support costs.

Summary

As stated earlier in this chapter, a model is only valid for a specific purpose and only within a certain set of parameters. Sensitivity analysis was conducted using OSCATE to determine the purpose and parameters of the model. The variables that were used in this analysis included MTBF, RIP, PAMH/IMH/RMH, DCOND, and TARGAVAL. The effect of changes in each of these variables on the total logistics support cost was observed.

The changes that were made to MTBF had the greatest effect on total logistics support cost in the lower ranges of MTBF. The total logistics support cost followed an exponential curve in response to changes in MTBF. The changes in logistics support cost as the result of changes in RIP indicated a linear relationship of decreasing LSC to increasing values of RIP. However, it was pointed out

that careful consideration should be given to other factors when conducting tradeoff studies using RIP. Increases in in-place maintenance manhours (PAMH, IMH, and RMH) resulted in a linear increase in the total logistics support cost. As the DCOND rate increased the total logistics support cost decreased. However, this relationship is dependent upon the unit cost of the TRUs. Variations in TARGAVAL resulted in a negative linear relationship with total logistics support cost at the lower values of TARGAVAL and exhibited an exponential relationship as the value of TARGAVAL approached 1.

It should be noted that the results obtained are dependent upon the structure of OSCATE, the assumptions that were made in exercising the model, and on the accuracy of the data base used. The final chapter of this thesis will discuss potential model use, model limitations, and recommend areas for further study.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

The Operation and Support Cost Model for Automatic Test Equipment (OScate) developed as a result of this study has the potential for being a valuable tool in ATE acquisition. However, the model must first be validated. After validation, potential model users must be instructed on when, where, and how to use the model, considering model assumptions and limitations. These issues will be discussed in this chapter, which will end with recommendations for further research in the area of Life Cycle Cost (LCC) models for ATE.

Potential Model Uses

The OSCATE model developed in this research effort can be used to estimate and measure operation and support costs for ATE. Since ATE is the major cost item within support equipment and operation and support costs make up 60 percent or more of Life Cycle Cost, OSCATE can be an important addition to LCC techniques applied to ATE. For example, it can serve as a useful tool in evaluating ATE operation and support costs during source selection of ATE contractors.

OSCATÉ can also be used to aid in award fee determination or establish criteria for penalty clauses, when the model is used in conjunction with the Logistics Support Cost Commitments discussed in Chapter II. Additionally, OSCATE can be used for evaluation of engineering change proposals, where C&S cost changes are a consideration in ECP approval.

Other areas where OSCATE may prove useful include the investigation of tradeoffs concerning technician training, the evaluation of repair-discard options, and the determination of optimum balances between preventive, remedial, and on-condition maintenance.

Model Limitations

The OSCATE model, not unlike other accounting models, has limitations the potential user must be aware of. OSCATE does not necessarily project the actual increment of LSC that results from introducing the proposed ATE into the Air Force inventory. It is only a representative figure for real costs of logistics support. The model only gives a summary of the cost impacts of projected demands for support resources, but will not address the interdependence of those resources. The user should understand that the model is not meant to be a substitute for comprehensive support planning.

• When using this model, the risk considerations concerning estimation and verification of TLSCs and MLSCs, respectively, mentioned in Chapter III, should be understood. In order to reduce the statistical risk involved during verification, the number of parameters to be verified can be reduced or the parameters from an aggregate number of TRUs can be verified instead of treating individual TRUs.

Other Considerations in Model Use

One of the prime considerations when using this model in the acquisition process is the problem associated with the government obtaining variable data for use in the OSCATE model. Therefore, it is recommended that the OSCATE model be provided to the prospective contractors as part of the Request for Proposal. The contractor should be required by the Statement of Work (SOW) or Work Specification to use OSCATE to obtain operation and support cost estimates which would become contractually binding should the contractor be selected as the full-scale development contractor.

Other considerations when using the OSCATE model are availability of data needed to exercise the model, user understanding and acceptance of the model, and knowledge of the model assumptions.

Availability of Data

Plans should be made as early as possible to obtain data necessary to establish values for all the variables which will be used when exercising the model. One of the main problems encountered during the development of OSCATE was the availability of data. The data used to exercise the model was primarily field data obtained from the D056 Product Performance Collection System. This data, part of the Maintenance Data Collection System (AFM 66-1), was not readily available in a useable form. A significant amount of time and effort was required to extract and combine data from several computer output products. In addition, several data items such as the total operating hours of the equipment, the condemnation rate, and the fraction of repair in place maintenance actions were not available because they are not normally included items in the Maintenance Data Collection System. Another aspect of data limitation was the problem of maintaining control by functional rather than systemic areas.

The field data which was obtained was primarily broken out in accordance with the weapon system ATE Work Unit Code Manual (29). One notable exception to this was in the area of calibration requirements. The work unit codes assigned to TRUs requiring calibration were different than those listed in the weapon system ATE manual. Furthermore, if the calibrated TRU is used on several other

systems, it is virtually impossible to discern the calibration actions attributable to each specific system.

This same type of problem occurs under the DO56 system where an item of a particular stock class is sent to the depot for repair or calibration. When the repair or calibration is completed, the action is charged against that particular stock class and not against the Automatic Test Equipment. By collecting data functionally rather than by system, valuable information is obscured if not totally lost.

User Understanding and Acceptance of the Model

First and foremost the potential user of OSCATE should be acquainted with the purpose for which the model was developed. OSCATE is intended as a tool in the Life Cycle Cost (LCC) technique which has as its ultimate goal the design, development, and acquisition of systems--in this case ATE--with lower life cycle costs. In addition, the user of this model should be familiar with variables involved, the sensitivity of the model, and the values of parameters that are furnished to a contractor. The values of parameters like TARGAVAL furnished to a contractor should be responsible, meaningful, and attainable.

It is not enough for a contractor to use this model for estimating O&S costs of his equipment if provisions have not been made to verify this estimate. Therefore, it

it is important that an evaluation plan be established which the contractors understand, is acceptable to both parties and which can be verified. The contractor, also as a user of the OSCATE, has to have complete knowledge of how his results are to be evaluated.

Model Assumptions

The assumptions which were made in development of this model should not be taken lightly. Neglecting these assumptions can lead to misinterpretation of the model output and could lead to problems or disagreements between the government and the contractor. Both parties should be aware of the assumptions since they form the basis for some of the most critical computations. Such is the case of the assumptions which were made (reference Chapter IV) in calculating the TRU spares requirements. Other assumptions regarding (1) variables such as the Peak Operating Hours (POH), (2) the maintenance technician quantities and skills, and (3) the maintenance concept, have to be considered when OSCATE is to be employed.

Recommendations for Further Study

During the development of the model several topics were considered for research which were outside the scope of this thesis, but warrant further investigation. Emphasis should be placed upon these areas when conducting future research. These areas are:

1. Model validation
2. Development of Equation C_9 for software
3. Test assumptions regarding availability of ATE
4. Establishment of an information system to provide data for the model.

Model Validation

Now that OSCATE has been developed, the task of validation remains to be performed. The purpose of validation is to test how well the model represents the real world. This test is necessary to determine if any modifications and/or adjustments need to be made to the model and to provide some level of confidence in OSCATE estimates.

It is suggested that future researchers choose an existing weapon system using ATE and apply OSCATE to historical data obtained on that system. Predicted costs from the model should be compared to actual costs established from the data. In addition to the sources of data cited in this research, it is suggested that more complete data be obtained from the operational bases, contractor, and applicable depots.

Additionally, OSCATE can be further validated by comparing its output with that of parallel modeling efforts conducted in the civilian sector.

Development of Equation C₉ for Software

An equation for determining the cost of software used in support of ATE should be developed. OSCATE in its present form does not address the cost of ATE software due to the limited availability of data in this area. Indications are, however, that software costs are large and will increase as ATE becomes more sophisticated.

One possible approach would be to contact several contractors engaged in software development to gain insight into how they estimate software costs. Additionally, the Computer Research Branches at the ALCs could be considered as possible sources of expertise. Data concerning actual software costs could be obtained from contractors, the support equipment SPO, and specific weapon system SPOs.

Test of Assumption Regarding Availability of ATE

Presently, in the calculation of the TRU spares requirements, the assumption is that any failed TRU will render the ATE inoperable. This is a simplifying assumption that is valid only when ATE is required to be 100 percent operational. If the ATE could be considered functional at operational levels less than 100 percent, it would be desirable to develop the capability in OSCATE to identify and prioritize those TRUs that are most critical. With this capability ATE managers could then give special attention to

critical TRUs in order to prevent unacceptable levels of operability.

APPENDICES

APPENDIX A
BASIC LSC MODEL FRAMEWORK

The following is an outline of a basic LSC framework (6:1):

$$\begin{aligned}
 C_1 &= \text{Cost of initial spare items} \\
 &= (\text{Cost of base repair pipeline spares}) + \\
 &\quad (\text{Cost of depot repair pipeline spares}) \\
 &= (M) (STK) (UC) + \frac{(PFFH) (UF) (QPA) (1-RIP) (NRTS)}{MTBF} (DRCT) (UC) \\
 \\
 C_2 &= \text{Cost of on-equipment maintenance} \\
 &= (\text{total mean number of failures}) \times (\text{average on-equipment repairs cost per failure})
 \end{aligned}$$

$$= \left[\frac{(TFFH) (UF) (QPA)}{(MTBF)} \right] \left[(PAMH) + (RIP) (IMH) + (1-RIP) (RHM) \right] (BLR)$$

$$\begin{aligned}
 C_3 &= \text{Cost of off-equipment maintenance} \\
 &= (\text{total mean number of off-equipment repairs}) \times \\
 &\quad (\text{average cost per off-equipment repair}) \\
 &= \left[\frac{(TFFH) (UF) (QPA) (1-RIP)}{MTBF} \right] \left[(RTS) (BMH) (BLR+BMR) + (NRTS) \right. \\
 &\quad \left. (DMH) (DLR+DMR) \right]
 \end{aligned}$$

where:

BLR is the base labor rate (\$/manhour);

BMH is the average number of manhours to perform intermediate level maintenance on a removed item;

DLR is the depot level rate;

DMH is the average number of manhours to perform depot level maintenance on a removed item;

DMR is the depot consummable material consumption rate;

DRCT is the average depot repair cycle time in months;

IMH is the average number of manhours to perform corrective maintenance of the item in place or on line;

M is the number of operating locations;

MTBF is the mean time between failures in operating hours;

NRTS is the fraction of removed items expected to be returned to depot for repair;

PFFH is the peak force flying hours; the expected total fleet flying hours for one month during the peak usage period;

QPA is the quantity of like items within the parent system;

RIP is the fraction of item failures which can be repaired in place or on line;

RMH is the average number of manhours to isolate a fault, remove and replace the item, and verify restoration of the system to operational status;

RTS is the fraction of removed items expected to be repaired at the base;

STK is the stock level of the item at each base;

TFFH is the expected total force flying hours over the program inventory usage period;

UC is the negotiated unit cost of a spare item as of the end of the verification test; and

UF is the ratio of operating hours to flying hours for the item.

BLR, BMR, DLR, DMR, DRCT, M, PFFH, and TFFH parameters are supplied by the government. BMH, DMH, IMH, MTBF, NRTS,

PAMH, QPA, RIP, RMH, RTS, UC and UF parameters are supplied by the contractor. The rest of the parameters are computed by the model.

APPENDIX B
VARIABLE MATRIX

ATE System Variables	Where Found		Source of Data	
	Actual Data	Existing Models	Government	Contractor
CARF	X			X
IMC	X	X	X	
M	X	X	X	
MRF	X	X	X	
MRO	X	X	X	
NSYS	X	X		X
OS	X	X	X	
OST	X	X	X	
PIUP	X	X	X	
PMB	X	X	X	
PMD	X	X	X	
POH		X		X
PSC	X	X	X	
PSO	X	X	X	
RMC	X	X	X	
SA	X	X	X	

ATE System Variables Continued	Where Found		Source of Data	
	Actual Data	Existing Models	Government	Contractor
SR	X	X	X	
TARGAVAL		X	X	
TD	X	X	X	
TOH	X	X		X
TR	X	X	X	
TRB	X	X	X	
TRD	X	X	X	
UEBASE	X	X	X	

Subsystem Variables	Where Found		Source of Data	
	Actual Data	Existing Models	Government	Contractor
BCA		X		X
BLR	X	X	X	
CASYS	X			X
CIVLR	X		X	
DAA	X	X	X	
DCA		X		X
DLR	X	X	X	
DMR	X	X	X	
DPA		X		X
DRCT	X	X	X	
H	X	X		X
JJ	X	X		X
N	X	X		X
SCI	X			X
SCMH	X			X

Subsystem Variables Continued	Where Found		Source of Data	
	Actual Data	Existing Models	Government	Contractor
SMH	X	X		X
SYSNOUN		X		X
TCB	X	X		X
TDC	X	X		X
TE	X	X		X
XSYS	X	X		X

TRU Variables	Where Found		Source of Data	
	Actual Data	Existing Models	Government	Contractor
CATRU	X			X
CI	X		X	X
CI I	X			X
CI I LR	X			X
CI LR	X			X
CIV	X			X
DBC MH	X	X		X
DCOND		X		X
DMC	X	X		X
DMH	X	X		X
FICR	X			X
FIICR	X			X
FIVCR	X			X
IMH	X	X		X
K	X	X		X

TRU Variables Continued	Where Found		Source of Data	
	Actual Data	Existing Models	Government	Contractor
MTBF	X	X		X
PAMH	X	X		X
PP	X	X		X
QPA	X	X		X
RIP		X		X
RMH	X	X		X
SP	X	X		X
TRUCI	X			X
TRUCMH	X			X
TRUNOUN	X	X		X
UC	X	X		X
W	X	X		X
XTRU	X	X		X

Support Equipment Variables	Where Found		Source of Data	
	Actual Data	Existing Models	Government	Contractor
CAD	X	X		X
COD	X	X		X
DOWN		X		X
DUR	X	X		X
XSE	X	X	X	

APPENDIX C
VARIABLE DEFINITIONS

ATE System Variables*

- CARF - The fraction of units to be calibrated that require repair. (C)
- IMC - Initial management cost to introduce a new line item of supply (ASSEMBLY or piece part) into the Air Force inventory. (S=\$166.25/item) (AFLCR 173-10)
- M - Number of intermediate repair locations (operating bases). (P)
- MRF - Average manhours per failure to complete off-equipment maintenance records. (S=.24 hours)
- MRO - Average manhours per failure to complete on-equipment maintenance records. (S=.08 hours)
- NSYS - Number of systems within the ATE.
- OS - Fraction of total force deployed to overseas locations. (P)
- OST - Weighted average Order and Shipping Time in months. The elapsed time between the initiation of a request for a serviceable item and its receipt by the requesting activity. For CONUS locations, S=0.394 months (12 days) input as OSTCON. For overseas locations, S=0.526 months (16 days) input as OSTOS. (AFLCR 173-10)
 $OST = (OSTCON)(1-OS) + (OSTOS)(OS)$

NOTES: (C) = contractor-furnished
(S) = Government-furnished standard value
(P) = Government-furnished program-peculiar value
(AFLCR 173-10) = denotes data source is AFLCR 173-10; all cost factors have been escalated from their respective base year dollars to common FY79 dollars using the O&M factors found in AFR 173-10, Vol I, Table 49.

* The categorization of variable definitions is consistent with variable input requirements of the computer model.

- PIOP - Operational service life of the ATE in years.
(Program Inventory Usage Period) (P)
- PMB - Direct productive manhours per man per year at
base level (includes "touch time," transporta-
tion time, and setup time). (S=1728 hours/man/
year) (AFLCR 173-10)
- PMD - Direct productive manhours per man per year at
the depot (includes "touch time," transportation
time, and setup time). (S=1728 hours/man/year)
AFLCR 173-10)
- POH - Peak Operating Hours--expected operating hours
for one month during the peak usage period.
(C)
- PSC - Average packing and shipping cost to CONUS loca-
tions. (S=\$0.72/pound) (AFLCR 173-10)
- PSO - Average packing and shipping cost to overseas
locations. (S=\$1.49/pound) (AFLCR 173-10)
- RMC - Recurring management cost to maintain a line
item of supply (assembly or piece part) in the
wholesale inventory system. (S=\$166.25/item/
year) (AFLCR 173-10)
- SA - Annual base supply line item inventory manage-
ment cost. (S=\$8.39/item) (AFLCR 173-10)
- SR - Average manhours per failure to complete sup-
ply transaction records. (S=.25 hours)
- TARGAVAL - Base-level spares availability objective for
ATE. (P)
- TD - Average cost per original page of technical
documentation. The average acquisition cost
of one page of the reproducible source document
(does not include reproduction costs).
(S=\$200.07/page) (AFLCR 173-10)
- TOH - Expected Total Operating Hours over the Pro-
gram Inventory Usage Period. (C)
- TR - Average manhours per failure to complete
transportation transaction forms. (S=.16 hours)

- TRB - Annual Turnover rate for base personnel.
(S=.134)
- TRD - Annual Turnover rate for depot personnel.
(S=.15)
- UEBASE - The number of unit equivalent ATE per operating base. (P)

Subsystem Variables*

- BCA - Total cost of additional items of common base shop support equipment per base required for the system. (C)
- BLR - Base labor rate, including indirect labor, indirect material and overhead. (S=\$15.18/hour) (AFLCR 173-10)
- CASYS - Number of systems to be calibrated. (C)
- CIVLR - Labor rate at the Class IV PMEL lab. (P)
- DAA - Available work time per man at the depot in manhours per month. (S=168 hours) (AFLCR 173-10)
- DCA - Total cost of additional items of common depot support equipment required for the system. (C)
- DLR - Depot labor rate, including other direct costs, overhead and G&A. (S=\$26.20/hour) (AFLCR 173-10)
- DMR - Depot consumable material consumption rate. Includes minor items of supply (nuts, washers, rags, cleaning fluid, etc.) which are consumed during repair of items (S=\$2.11/hour) (AFLCR 173-10)
- DPA - Total cost of peculiar depot shop support equipment per base required for the system which is not directly related to repair of specific TRUs or when the quantity required is independent of the anticipated workload (such as overhead cranes and shop fixtures). (C)

- DRCT - Weighted average Depot Repair Cycle Time in months. The elapsed time for a NRTS item from removal of the failed item until it is returned to depot serviceable stock. This includes the time required for base-to-depot transportation and handling and the shop flow time within the specialized repair activity required to repair the item. For CONUS locations, S=1.40 months (52 days) for organic repair, S=2.06 (62 days) for contractual repair, input as DRCTC. For overseas locations, S=1.90 months (57 days) for organic repair, S=2.20 months (66 days) for contractual repair, input as DRCTO. (AFLCR 173-10)
- $$DRCT = (DRCTC) (1-OS) + (DRCTO) (OS)$$
- H - Number of pages of depot level technical orders and special repair instructions required to maintain the system. (C)
- JJ - Number of pages of organizational and intermediate level technical orders required to maintain the system. (C)
- N - Number of different TRUs within the ATE. (C)
- SCI - Scheduled calibration interval for the system. (C)
- SCMH - Manhours required to perform calibration. (C)
- SMH - Average manhours to perform a scheduled periodic or phased inspection of the system. (C)
- SMI - Operating hour interval between scheduled periodic or phased inspections on the system. (C)
- SYSNOUN - Name of the system--up to 60 alphanumeric characters. (C)
- TCB/ - Cost of peculiar training per man at base level including instruction and training materials. (C)
- TCD - Cost of peculiar training per man at the depot including instruction and training materials. (C)

- TE - Cost of peculiar training equipment required for the system. (C)
- XSYS - System identification. The assigned five-character alphanumeric Work Unit Code of the system. (C)

TRU Variables*

- CATRU - Number of TRUs requiring calibration. (C)
- CI - Factor which is 0 if no calibration at Class I lab is required or 1 if calibration at Class I lab is required. (C)
- CII - Factor which is 0 if no calibration at Class II lab is required or 1 if calibration at Class II lab is required. (C)
- CIILR - Labor rate at a Class II lab. (C)
- CILR - Labor rate at a Class I lab. (C)
- CIV - Factor which is 0 if no calibration at Class IV lab is required or 1 if calibration at Class IV lab is required. (C)
- DBCMH - Average manhours to perform a shop bench check, screening, and fault verification on a removed TRU prior to initiating repair action or condemning the item. (C)
- DCOND - Fraction of TRUs returned to the depot for repair expected to result in condemnation at depot level. (C)
- DMC - Average cost per failure for a TRU repaired at depot level for stockage and repair of lower level assemblies expressed as a fraction of the TRU unit cost (UC). This is the implicit repair disposition cost for a TRU representing labor, material consumption, and stockage/replacement of lower indenture reparable components within the TRU (e.g., shop replaceable units or modules). (C)
- DMH - Average manhours to perform intermediate-level (base shop) maintenance on a removed TRU including fault isolation, repair, and verification. (C)

FICR	- Manhours spent on repair of items to be calibrated at Class I lab. (C)
FIICR	- Manhours spent on repair of items to be calibrated at Class II lab. (C)
FIVCR	- Manhours spent on repair of items to be calibrated at Class IV lab. (C)
IMH	- Average manhours to perform corrective maintenance of the TRU in place or on line without removal including fault isolation, repair, and verification. (C)
K	- Number of line items of peculiar shop support equipment used in repair of the TRU. (C)
MTBF	- Mean Time Between Failures in operating hours of the TRU in the operational environment. (C)
PAMH	- Average manhours expended in place on the installed system for Preparation and Access for the TRU for example, jacking, unbuttoning, removal of other units and hookup of support equipment. (C)
PP	- Number of new "P" coded consumable items within the TRU. (C)
QPA	- Quantity of like TRUs within the parent system. (Quantity per Application) (C)
RIP	- Fraction of TRU failures which can be repaired in place or on line without removal. (C)
RMH	- Average manhours to fault isolate, remove, and replace the TRU on the installed system and verify restoration of the system to operational status. (C)
TRUCI	- Calibration interval for a TRU. (C)
TRUCMH	- Manhours required to calibrate a TRU. (C)
TRUNOUN	- Word description or name of the TRU--up to 60 alphanumeric characters. (C)
UC	- Expected unit cost of the TRU at the time of initial provisioning. (C)

- W - TRU weight in pounds. (C)
- XTRU - TRU identification. The assigned five-character alphanumeric Work Unit Code of the TRU. (C)

Support Equipment Variables*

- CAD - Cost per unit of peculiar support equipment for the depot shop. (C)
- COD - Annual cost to operate and maintain a unit of support equipment at depot level expressed as a fraction of the unit cost (CAD). (C)
- DOWN - Fraction of downtime for a unit of support equipment for maintenance and calibration requirements. (C)
- DUR - Combined utilization rate for all like items of support equipment at depot level. (C)
- XSE - SE identification--up to 20 alphanumeric characters. (C)

APPENDIX D
COMPUTER PROGRAM


```

1000**RUN **-(CORE=30K)
1010C*****
1020C***** OSCATE *****
1030C*****
1040    DIMENSION TRUMAT(100,20),SEMAT(100,9),SYSMAT(30,13),SECUM(50,5)
1050    DIMENSION SORTRU(100,20),EQTOT(12),AVTAB(1000,5),UCTAB(100)
1060    DIMENSION KEY(1),MODE(1),LINK(1000),SETAB(50,2)
1070    CHARACTER XSYS*5(30),XTRU*5(100,2),XSE*20(100),SORTXTRU*5(100,2)
1080    CHARACTER SYSNOUN*60(30),TRUNOUN*60(100),SETRU*5(100,2),CANS*5
1090    CHARACTER XSECUM*20(50),DATE*8,CMAT*5(1,1)
1100    DATA SYSMAT,TRUMAT,EQTOT/2331*0./
1110    REAL H,IMC,IMH,JJ,LS,M,MRO,MRF,NTBF
1120    CALL FPARAM(1,80)
1130    TOTLSC=0.
1140    AVI=1.
1150    NUMAVT=0
1160    MAXAVT=1000
1170C*****
1180C***** READ ATE VARIABLES *****
1190C*****
1200    READ(10,2) LN, TOH,POH,PIUP,M,OS,NSYS,UEBASE,TARGAVAL
1210    READ(10,2) LN, OSTCON,OSTOS,IMC,RMC,PSC,PSO,TRB,TRD
1220    READ(10,2) LN, TD,SA,MRO,MRF,SR,TR,PMB,PMD,CARF
1230    2 FORMAT(V)
1240    OST=OSTCON*(1.-OS)+OSTOS*OS
1250    IF(NSYS.LE.50) GO TO 30
1260    PRINT 3
1270    3 FORMAT("REDIMENSION SYSMAT, XSYS, SYSNOUN")
1280    STOP
1290    30 INEXT=1
1300    JNEXT=1
1310C*****
1320C***** READ SYSTEM VARIABLES *****
1330C*****
1340    DO 1000 IS=1,NSYS
1350    READ(10,2) LN,XSYS(IS),SYSNOUN(IS)
1360    READ(10,2) LN,BCA,DCA,DPA,N
1370    READ(10,2) LN,H,JJ,SMH,SMI,TCB,TCD,TE
1380    READ(10,2) LN,BLR,DLR,DNR,DAA,DRCTC,DRCTO
1390    READ(10,2) LN,SCI,SCMH,CIVLR,CASYS
1400    DRCT=DRCTC*(1.-OS)+DRCTO*OS
1410    SYSMAT(IS,2)=TOH*SMH*BLR/SMI
1420    SYSMAT(IS,5)=(1+0.1*PIUP)*(DCA+DPA+M*BCA)
1430    C6X=TCB*(1.+(PIUP-1.)*TRB)/(PIUP*PMB)
1440    C6Y=TCD*(1.+(PIUP-1.)*TRD)/(PIUP*PMD)
1450    SYSMAT(IS,6)=C6X*TOH*SMH/SMI+TE
1460    SYSMAT(IS,7)=TOH*BLR*(MRO+0.1*(SR+TR))/SMI+TD*(JJ+H)
1470    IF(CASYS.EQ.0) GO TO 34
1480    SYSMAT(IS,8)=365*PIUP*CIVLR/SCI
1490    34 IF(N.EQ.0) GO TO 1000
1500C*****
1510C***** READ TRU VARIABLES *****
1520C*****

```



```

1530      IMAX=INEXT+N-1
1540      IF(IMAX.LE.100) GO TO 38
1550      PRINT 37
1560 37  FORMAT("REDIMENSION TRUMAT,XTRU,TRUNOUN, SORTRU, SORTXTRU,KC,KD,KE")
1570      STOP
1580 38  DO 999 I=INEXT,IMAX
1590      READ(10,2) LN,XTRU(I,1),TRUNOUN(I)
1600      READ(10,2) LN,QPA,UC,MTBF,RIP,DCOND,DMC
1610      READ(10,2) LN,PAMN,IMH,AMH,DBCMH,DMH,W,PP,SP,K
1620      READ(10,2) LN,TRUCI,TRUCMH,CILR,CILR,FICR,CII,CII,CIV,
1630      FIVCR,FIVCR,CATRU
1640      IF(CATRU.EQ.0) GO TO 39
1650      CAL1=365*PIUP*QPA*TRUCMH*((CI*CILR+CII*CILR+
1660      CIV*CIVLR)/TRUCI)
1670      CAL2=365*PIUP*QPA*CARF*((CI*CILR+FICR+CII*CILR+FIVCR+
1680      CIV*CIVLR)/TRUCI)
1690      TRUMAT(I,20)=CAL1+CAL2
1700 39  XTRU(I,2)=XSYS(IS)
1710      PKGEN=POH*QPA/MTBF
1720      TRUMAT(I,9)=PKGEN
1730      PKOEGEN=PKGEN*(1.-RIP)
1740      TRUMAT(I,10)=PKOEGEN
1750      TOTGEN=TOH*QPA/MTBF
1760      TRUMAT(I,11)=TOTGEN
1770      TOTOEGEN=TOTGEN*(1.-RIP)
1780      TRUMAT(I,12)=TOTOEGEN
1790      DMDMEAN=PKOEGEN*OST/M
1800      TRUMAT(I,14)=DMDMEAN
1810C.....
1820***COMPUTE MIN BASE TRU SPARES STOCK LEVELS SUCH THAT***
1830*** EACH TRU HAS AN AVAILABILITY>TARGAVAL. COMPUTE ***
1840*** ADD'L INFO REQUIRED FOR MARGINAL ANALYSIS "BUYS." ***
1850.....
1860      XBO=DMDMEAN
1870      PROBX=EXP(-DMDMEAN)
1880      STK=0.
1890      STKI=0.
1900      SUM=0.
1910      UCTAB(1)=UC
1920      AVO=(1.-XBO/(QPA*UEBASE))*QPA
1930      AVI=AVI+AVO
1940      AV=AVO
1950      TRUMAT(I,17)=0
1960      TRUMAT(I,15)=XBO
1970      TRUMAT(I,16)=AV
1980 41 IF(AV.GT.0.99999) GOTO 43
1990      SUM=SUM+PROBX
2000      XBO=XBO+SUM-1.
2010      STK=STK+1.
2020      PROBX=PROBX*DMDMEAN/STK
2030      AV=(1.-XBO/(QPA*UEBASE))*QPA
2040      RIMP=AV/AVO
2050      SV=ALOG(RIMP)/UC
2060      AVO=AV

```

```

2070      IF(AV .GT. TARGAVAL) GO TO 42
2080      STKI=STKI+1.
2090      AVI=AVI*RIMP
2100      TRUMAT(1,13)=XBO
2110      TRUMAT(1,16)=AV
2120      GO TO 41
2130      42 NUMAVT=NUMAVT+1
2140      IF(NUMAVT .LE. MAXAVT) GO TO 44
2150      PRINT 43
2160      43 FORMAT("REDIMENSION AVTAB, LINK AND RESET MAXAVT")
2170      STOP
2180      44 AVTAB(NUMAVT,1)=SV
2190      AVTAB(NUMAVT,2)=RIMP
2200      AVTAB(NUMAVT,3)=FLOAT(1)
2210      AVTAB(NUMAVT,4)=XBO
2220      AVTAB(NUMAVT,5)=AV
2230      GOTO 41
2240      45 TRUMAT(1,17)=STKI
2250      DPIPE=CEIL(PKOEGEN*(1-DCOND)*DRCT)
2260      TOTCOND=CEIL(TOTOEGEN*DCOND)
2270      TRUMAT(1,18)=DPIPE
2280      TRUMAT(1,19)=TOTCOND
2290      TRUMAT(1,1)=UC*(STKI*M+DPIPE+TOTCOND)
2300      TRUMAT(1,2)=TOTGEN*(PAMH+RIP*INH*(1.-RIP)*RMH)*BLR
2310      TRUMAT(1,3)=TOTOEGEN*((DSCMH*DLR*(1-DCOND)
2320      *DMH*(DLR+DMH)+DMC*UC)+2*((1.-OS)*PSC+OS*PSO)*1.35*W)
2330      TRUMAT(1,4)=(IMC+PIUP*RMH)*(1.+PP)+M*SA*PIUP
2340      47 TRUMAT(1,6)=C6X*TOTGEN*(PAMH+RIP*INH*(1.-RIP)*RMH)+
2350      C6Y*TOTOEGEN*(DSCMH*(1.-DCOND)*DMH)
2360      TRUMAT(1,7)=TOTGEN*(MRO+(1.-RIP)*(SR+TR))*BLR
2370      IF (K.EQ.0) GO TO 999
2380C*****
2390C***** READ SE VARIABLES *****
2400C*****
2410      JMAX=JNEXT+K-1
2420      IF(JMAX.LE.100) GO TO 49
2430      PRINT 48
2440      48 FORMAT("REDIMENSION SEMAT,XSE,SETRU")
2450      STOP
2460      49 DO 998 J=JNEXT,JMAX
2470      READ(10,2) LN,XSE(J),CAD,COD,DUR,DOWN
2480      SETRU(J,1)=XTRU(1,1)
2490      SETRU(J,2)=XTRU(1,2)
2500      SEMAT(J,5)=PKOEGEN*(DSCMH*(1-DCOND)*DMH)/(DUR*DAA*(1.-DOWN))
2510      SEMAT(J,7)=CAD
2520      SEMAT(J,9)=COD
2530      998 CONTINUE
2540      JNEXT=JNEXT+K
2550      999 CONTINUE
2560      INEXT=INEXT+N
2570      1000 CONTINUE
2580*****
2590*** "BUY" ADDITIONAL SPARES SO THAT PRODUCT ***
2600*** AVAILABILITY FOR ALL TRUS>TARGAVAL ***

```

```

2610 *****
2620     KEY(1)=1
2630     MODE(1)=2
2640     CALL SORTL(AVTAB,NUMAVT,3,KEY,MODE,1,MAXAVT,1,LINK,CMAT,1,0)
2650     NUMPTR=0
2660     60 IF(AVI .GT. TARGAVAL) GO TO 65
2670     NUMPTR=NUMPTR+1
2680     RIMP=AVTAB(NUMPTR,2)
2690     IFLUPT=AVTAB(NUMPTR,3)
2700     TRUMAT(IFLUPT,15)=AVTAB(NUMPTR,4)
2710     TRUMAT(IFLUPT,16)=AVTAB(NUMPTR,5)
2720     TRUMAT(IFLUPT,17)=TRUMAT(IFLUPT,17)+1.
2730     TRUMAT(IFLUPT,1)=TRUMAT(IFLUPT,1)+UCTAB(IFLUPT)*M
2740     AVI=AVI+RIMP
2750     GOTO 60
2760     65 CONTINUE
2770C *****
2780C ***** ESTABLISH SECUM *****
2790C *****
2800     IF(J.EQ.0) GO TO 91
2810     JH=0
2820     DO 90 JE=1,J
2830     IF(XSE(JE).EQ."0") GO TO 90
2840     UFLU=0.
2850     USYS=0.
2860     JH=JH+1
2870     IF(JH.LE.50) GO TO 84
2880     PRINT 82
2890     82 FORMAT("REDIMENSION SECUM, XSECUM, SETAB")
2900     STOP
2910     84 XSECUM(JH)=XSE(JE)
2920     XSE(JE)="0"
2930     SCCUM(JH,4)=SEMAT(JE,5)
2940     JH=JH+1
2950     DO 80 JF=JH,J
2960     IF(XSE(JF).NE.XSECUM(JH)) GO TO 80
2970     XSE(JF)="0"
2980     SECUM(JH,4)=SECUM(JH,4)+SEMAT(JF,5)
2990     UFLU=1.
3000     IF(SETRU(JF,2).EQ.SETRU(JE,2)) GO TO 80
3010     USYS=1.
3020     80 CONTINUE
3030     SECUM(JH,5)=CEIL(SECUM(JH,4))
3040     CSQ=SECUM(JH,5)*SEMAT(JE,7)*(1.+PIUP*SEMAT(JE,9))
3050     IF(USYS.GT.0.) GO TO 89
3060     IF(UFLU.GT.0.) GO TO 87
3070     DO 86 JC=1,I
3080     IF(XTRU(JC,1).NE.SETRU(JE,1)) GO TO 86
3090     TRUMAT(JC,5)=TRUMAT(JC,5)+CSQ
3100     SETAB(JH,1)=1.
3110     SETAB(JH,2)=FLOAT(JC)
3120     GO TO 90
3130     86 CONTINUE
3140     87 DO 88 IQ=1,NSYS

```



```

3150      IF(XSYS(IQ).NE.SETRU(JE,2)) GO TO 88
3160      SYSMAT(IQ,5)=SYSMAT(IQ,5)+C5Q
3170      SETAB(JH,1)=2.
3180      SETAB(JH,2)=FLOAT(IQ)
3190      GO TO 90
3200      88 CONTINUE
3210      89 EQTOT(5)=EQTOT(5)+C5Q
3220      SETAB(JH,1)=3.
3230      90 CONTINUE
3240C*****
3250C***** COMPUTE TRU COST *****
3260C*****
3270      91 CALL DETACH(10,ISTAT, )
3280      DO 101 IB=1,1
3290      DO 92 IC=1,7
3300      TRUMAT(IB,8)=TRUMAT(IB,8)+TRUMAT(IB,10)
3310      92 CONTINUE
3320      TRUMAT(IB,8)=TRUMAT(IB,8)+TRUMAT(IB,20)
3330      101 CONTINUE
3340C*****
3350C***** COMPUTE SYSTEM COST *****
3360C*****
3370      DO 96 IK=1,NSYS
3380      DO 95 IL=1,1
3390      IF(XTRU(IL,2).NE.XSYS(IK)) GO TO 95
3400      SYSMAT(IK,8)=SYSMAT(IK,8)+TRUMAT(IL,20)
3410      DO 94 IN=1,7
3420      SYSMAT(IK,1M)=SYSMAT(IK,1M)+TRUMAT(IL,1M)
3430      94 CONTINUE
3440      95 CONTINUE
3450      96 CONTINUE
3460      DO 99 JN=1,NSYS
3470      DO 97 JP=1,8
3480      SYSMAT(JN,13)=SYSMAT(JN,13)+SYSMAT(JN,JP)
3490      97 CONTINUE
3500      99 CONTINUE
3510C*****
3520C***** COMPUTE ATE COST *****
3530C*****
3540      DO 98 IN=1,NSYS
3550      TOTLSC=TOTLSC+SYSMAT(IN,13)
3560      98 CONTINUE
3570      TOTLSC=TOTLSC+EQTOT(5)
3580C*****
3590C***** PRINT OUTPUT *****
3600C*****
3610      CALL YADATE(DATE)
3620      CALL YTIME(ETIME)
3630      PRINT 112,DATE,ETIME/100000+10000
3640      112 FORMAT(// "RUN OF ",A8," -- ",I4," HOURS")
3650      IF(TOTLSC.LT.10**6) GO TO 121
3660      IF(TOTLSC.LT.10**9) GO TO 117
3670      PRINT 115,TOTLSC/10**9
3680      115 FORMAT(// "TOTAL LSC = $",F7.2," BILLION.")

```

```

3690      GO TO 140
3700 117 PRINT 119,TOTLSC/10**6
3710 119 FORMAT(// "TOTAL LSC = $",F7.2," MILLION.")
3720      GO TO 140
3730 121 PRINT 123,TOTLSC
3740 123 FORMAT(// "TOTAL LSC = $",F7.0)
3750C*****
3760C***** KC,KD,KE MUST AGREE WITH DIMENSIONS OF TRUMAT AND XTRU *****
3770C*****
3780 140 DO 132 KC=1,100
3790      DO 130 KD=1,20
3800 130 SORTRU(KC,KD)=TRUMAT(KC,KD)
3810      DO 131 KE=1,2
3820 131 SORTXTRU(KC,KE)=XTRU(KC,KE)
3830 132 CONTINUE
3840      KEY(1)=13
3850      MODE(1)=2
3860      CALL SORTL(SYSMAT,MSYS,13,KEY,MODE,1,30,1,LINK,XSYS,1,1)
3870 KEY(1)=8
3880 MODE(1)=2
3890      CALL SORTL(SORTRU,IMAX,20,KEY,MODE,1,100,1,LINK,SORTXTRU,2,1)
3900 141 PRINT 142
3910 142 FORMAT(// "DO YOU WANT AN EXPLANATION OF YOUR AVAILABLE ",
3920      "OPTIONS?")
3930      READ 1003,CANS
3940      IF(CANS.NE."Y") GO TO 150
3950      PRINT 143
3960 143 FORMAT(// "OPTION 1 - TOTAL LSC BROKEN OUT BY EQUATION"/
3970      "OPTION 2 - ALL SYSTEMS RANKED ON COST"/
3980      "OPTION 3 - COST BREAKOUT BY EQUATION FOR A PARTICULAR SYSTEM"/
3990      "OPTION 4 - COST RANKING OF TRUS FOR A PARTICULAR SYSTEM"/
4000      "OPTION 5 - COST BREAKOUT BY EQUATION FOR A PARTICULAR TRU"/
4010      "OPTION 6 - DETAILED SUPPORT EQUIPMENT ANALYSIS"/
4020      "OPTION 7 - DETAILED SPARES ANALYSIS"/
4030      "OPTION 8 - MAINTENANCE GENERATIONS ANALYSIS"/
4040      "OPTION 9 - TRU WORK UNIT CODE/NOON CROSS-REFERENCE"/
4050      "OPTION 10 - STOP PROGRAM")
4060 150 PRINT 151
4070 151 FORMAT(// "WHICH OPTION?")
4080 155 READ:IANS
4090      IF(IANS.GT.10) GO TO 141
4100      GO TO (200,250,300,350,400,450,500,550,600,650),IANS
4110
4120C*****
4130C***** OUTPUT OPTION 1 *****
4140C*****
4150 200 DO 210 MP=1,8
4160      DO 210 MR=1,MSYS
4170 210 EQTOT(MP)=EQTOT(MP)+SYSMAT(MR,MP)
4180      PRINT 335
4190      PRINT 337,(EQTOT(MS),MS=1,5)
4200      PRINT 340
4210      PRINT 343,(EQTOT(MS),MS=6,8)
4220      GO TO 150

```



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4230
4240C*****
4250C*** OUTPUT OPTION 2 ***
4260C*****
4270 250 PRINT 260
4280 260 FORMAT(10X,"SYSTEM",4X,"COST(IN MILLIONS)",4X,
4290 "FRACTION OF TOTAL LSC")
4300 DO 280 IX=1,NSYS
4310     SYSMAT(IX,14)=SYSMAT(IX,13)/TOTLSC
4320     SYSCOST= SYSMAT(IX,13)/10**6
4330     PRINT 270,XSYS(IX),SYSCOST,SYSMAT(IX,14)
4340 270 FORMAT(11X,A5,F18.2,F19.2)
4350 280 CONTINUE
4360     GO TO 150
4370
4380C*****
4390C*** OUTPUT OPTION 3 ***
4400C*****
4410 300 PRINT 2006
4420 310 READ 2004,CANS
4430 DO 320 IE=1,NSYS
4440 IF(XSYS(IE).EQ.CANS) GO TO 330
4450 320 CONTINUE
4460     PRINT 2002
4470     GO TO 310
4480 330 PRINT 335
4490 335 FORMAT(/"EQUATION",10X,"#1",10X,"#2",10X,"#3",10X,"#4",10X,"#5")
4500     PRINT 337,(SYSMAT(IE,IC),IC=1,5)
4510 337 FORMAT(12X,5F12.0//)
4520     PRINT 340
4530 340 FORMAT("EQUATION",10X,"#6",10X,"#7",10X,"#8")
4540     PRINT 345,(SYSMAT(IE,ID),ID=6,8)
4550 345 FORMAT(12X,3F12.0//)
4560     GO TO 150
4570
4580C*****
4590C*** OUTPUT OPTION 4 ***
4600C*****
4610 350 PRINT 2006
4620 355 READ 2004,CANS
4630 DO 360 IP=1,NSYS
4640 IF(XSYS(IP).NE.CANS) GO TO 360
4650
4660     GO TO 365
4670 360 CONTINUE
4680     PRINT 2002
4690     GO TO 355
4700 365 PRINT:"HOW MANY TRUS TO BE INCLUDED IN RANKING?"
4710     READ:IAN5
4720     PRINT 370
4730 370 FORMAT(49X,"FRACTION OF"/16X,"TRU",12X,"COST",14X,
4740 "SYSTEM COST"//)
4750     PCTG=0.
4760     IR=0

```



```

4770      DO 380 IY=1,I
4780      IF(SORTXTRU(IY,2).NE.CANS) GO TO 380
4790      IR=IR+1
4800      PCT=SORTRU(IY,8)/SYSMAT(IP,13)
4810      PCTG=PCTG+PCT
4820      PRINT 375,IR,SORTXTRU(IY,1),SORTRU(IY,8),PCT
4830 375  FORMAT(I9,A11,F18.0,F18.2)
4840      IF(IR.EQ.IANS) GO TO 385
4850 380  CONTINUE
4860      IF(IR.EQ.IANS) GO TO 385
4870      PRINT: "THESE ARE ALL THE TRUS IN THIS SYSTEM."
4880      IANS=IR
4890 385  IPCTG=PCTG*100
4900      PRINT 390,IANS,IPCTG
4910 390  FORMAT(/"CONTRIBUTION OF TOP",I3,"TRUS=",I3,
4920      " PER CENT OF TOTAL SYSTEM COST.")
4930      PRINT 395,SYSMAT(IP,13)/10**6
4940 395  FORMAT("SYSTEM COST = 5",F8.2," MILLION.")
4950      GO TO 150
4960
4970C*****
4980C*** OUTPUT OPTION 5 ****
4990C*****
5000 400  PRINT 2008
5010 405  READ 2004,CANS
5020      DO 410 IU=1,I
5030      IF(SORTXTRU(IU,1).NE.CANS) GO TO 410
5040      GO TO 415
5050 410  CONTINUE
5060      PRINT 2002
5070      GO TO 405
5080 415  PRINT 420
5090 420  FORMAT(/"EQUATION",7X,"#1",12X,"#2",12X,"#3",12X,"#4")
5100      PRINT 425,(SORTRU(IU,IV),IV=1,4)
5110 425  FORMAT(7X,4F14.0//)
5120      PRINT 430
5130 430  FORMAT("EQUATION",7X,"#5",12X,"#6",12X,"#7",12X,"#8")
5140      PRINT 435,(SORTRU(IU,JL),JL=5,7),SORTRU(IU,20)
5150 435  FORMAT(7X,4F14.0)
5160      GO TO 150
5170
5180C*****
5190C*** OUTPUT OPTION 6 ****
5200C*****
5210 450  CONTINUE
5220      PRINT:"      COL 1 - SE IDENTIFICATION"
5230      PRINT:"      COL 2 - FRACTIONAL SE RQMT-BASE (COMPUTED)"
5240      PRINT:"      COL 3 - TOTAL SE RQMT-BASE (INTEGERIZED)"
5250      PRINT:"      COL 4 - FRACTIONAL SE RQMT-DEPOT (COMPUTED)"
5260      PRINT:"      COL 5 - TOTAL SE RQMT-DEPOT (INTEGERIZED)"
5270      PRINT 460
5280 460  FORMAT(/6X,"1",19X,"2",9X,"3",12X,"4",9X,"5"//)
5290      DO 480 JK=1,JN
5300      PRINT 470,XSECUM(JK),(SECUM(JK,JR),JR=2,5)

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5310 470 FORMAT(1X,A20,F8.2,F9.0,F14.2,F9.0)
5320 480 CONTINUE
5330 GO TO 150
5340
5350C *****
5360C ***** OUTPUT OPTION 7 *****
5370C *****
5380 500 PRINT 510
5390 510 FORMAT(28X,"TRUS"//4X,"WUC",7X,"DMDMEAN",8X,"X30",8X,
54006 "AV",11X,"STK",8X,"DPIPE",4X,"TOTCOND"//)
5410 DO 530 MU=1,I
5420 PRINT 520,XTRU(MU,1),(TRUMAT(MU,MX),MX=14,19)
5430 520 FORMAT(3X,A5,2F12.2,F12.4,3F12.0)
5440 530 CONTINUE
5450 PRINT 540,AVI
5460 540 FORMAT(1X//18X,"SYSTEM AVAILABILITY",F5.3)
5470 GO TO 150
5480C*****
5490C***** OUTPUT OPTION 8 *****
5500C*****
5510 550 PRINT 560
5520 560 FORMAT(31X,"PEAK",25X,"TOTAL"/10X,"PEAK",5X,"OFF-EQUIP",10X,
55306 "TOTAL",5X,"OFF-EQUIP"/7X,"WUC",10X,"GENS",7X,"GENS",14X,"GENS",
55406 8X,"GENS"//)
5550 DO 570 MV=1,I
5560 PRINT 565,XTRU(MV,1),(TRUMAT(MV,MY),MY=9,12)
5570 565 FORMAT(6X,A5,6X,F8.2,F11.1,F18.2,F12.2)
5580 570 CONTINUE
5590 GO TO 150
5600
5610C*****
5620C***** OUTPUT OPTION 9 *****
5630C*****
5640 600 PRINT 610
5650 610 FORMAT(//3X,"WUC",7X,"NOUN"//)
5660 DO 625 JZ=1,I
5670 PRINT 620,XTRU(JZ,1),TRUNOUN(JZ)
5680 620 FORMAT(2X,A5,3X,A60)
5690 625 CONTINUE
5700 GO TO 150
5710
5720 2002 FORMAT("IMPROPER IDENTIFICATION--RETYPE")
5730 2003 FORMAT(A1)
5740 2004 FORMAT(A5)
5750 2006 FORMAT("SYSTEM IDENTIFICATION?")
5760 2008 FORMAT("TXU IDENTIFICATION?")
5770
5780 650 STOP
5790 END
5800
5810C*****
5820C***** FUNCTION TO INTEGERIZE ROUNDING UP *****
5830C*****
5840 FUNCTION CEIL(X)

```



```

5850      Y=AIN(X)
5860      Z=X-Y
5870      IF(Z)...1
5880      CEIL=X
5890      RETURN
5900      1 CEIL=Y+1.
5910      RETURN
5920      END
5930C.....
5940 SUBROUTINE SORTL(A,NREC,NWPR,KEY,MODE,NKEY,ID,IP,LINK,CMAT,ICCOL,ICIND)
5950C.....
5960C A GENERAL PURPOSE SORTING SUBROUTINE USING LINK ADDRESSING
5970C:A      ARRAY OF SIZE NREC BY NWPR WHOSE ROWS COMPRISE
5980C:      THE DATA RECORDS TO BE SORTED
5990C:
6000C:NREC      NUMBER OF RECORDS=NUMBER OF ROWS OF A
6010C:
6020C:NWPR      NUMBER OF WORDS/RECORD=NUMBER OF COLUMNS OF A
6030C:
6040C:KEY      ARRAY OF SIZE NKEY WHOSE ELEMENTS ARE POINTERS TO
6050C:      THE COLUMNS OF A CONTAINING THE SORT KEYS
6060C:
6070C:MODE      ARRAY OF SIZE NKEY WHOSE ELEMENTS DEFINE THE
6080C:      ORDERING RELATION PLACED ON EACH KEY
6090C:      -2 INCREASING,UNSIGNED ORDER
6100C:      -1 INCREASING,SIGNED ORDER
6110C:      +1 DECREASING,UNSIGNED ORDER
6120C:      +2 DECREASING,SIGNED ORDER
6130C:
6140C:NKEY      NUMBER OF KEYS=SIZE OF ARRAYS KEY AND MODE
6150C:
6160C:ID      FIRST DIMENSION OF A IN THE PROGRAM CALLING UNIT
6170C:
6180C:IP      IF IP=0 THE RECORDS REMAIN IN THEIR ORIGINAL LOCATION,
6190C:      OTHERWISE, THE RECORDS ARE MOVED INTO THE DESIRED
6200C:      ORDER FOLLOWING THE SORT
6210C:
6220C:LINK      OUTPUT ARRAY OF SIZE NREC WHOSE ELEMENTS ARE
6230C:      POINTERS TO THE RECORDS IN A IN SORTED SEQUENCE
6240C:
6250C:CMAT      CHARACTER ARRAY OF SIZE NREC BY ICCOL WHOSE ROWS
6260C:      ARE MOVED IN CONJUNCTION WITH THE ROWS OF ARRAY A
6270C:
6280C:ICCOL      NUMBER OF COLUMNS OF CHARACTER VALUES IN ARRAY CMAT;
6290C:      EACH VALUE HAS 5 CHARACTERS
6300C:
6310C:ICIND      "FLAG" VALUE FOR SORTING CMAT;
6320C:      =0 DO NOT OPERATE ON CMAT
6330C:      NOT=0 REARRANGE THE VALUES IN CMAT
6340      DIMENSION A(ID,NWPR),KEY(NKEY),MODE(NKEY),LINK(NREC)
6350      INTEGER A,TEMP(100)
6360      CHARACTER CTEMP*5(20)
6370      CHARACTER CMAT*5(ID,ICCOL)
6380      LOGICAL EQV,P,Q

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```

6390      EQV(P,Q) = (P.AND.Q).OR.(.NOT.(P.OR.Q))
6400      NROW=NREC
6410      NCOL=NWPR
6420C
6430C INITIALIZE LINKS
6440C
6450      DO 10 I=1,NROW
6460      10 LINK(I)=I
6470      IF (NROW.EQ.1) RETURN
6480C
6490C FORM INITIAL INCREMENT
6500C
6510      M1=(NROW+5)/5
6520      M=1
6530      20 M=2*M
6540      IF (M.LT.M1) GO TO 20
6550      M=M-1
6560C
6570C BEGIN NEXT SORT PASS
6580C
6590      30 M1=M+1
6600      DO 100 J=M1,NROW
6610      LJ=LINK(J)
6620      I=J-M
6630C
6640C COMPARE KEYS IN RECORDS LINK(I) AND LINK(J)
6650C
6660      40 LI=LINK(I)
6670      DO 50 L=1,NKEY
6680      K=KEY(L)
6690      KI=A(LI,K)
6700      KJ=A(LJ,K)
6710      IF (EQV(KI.LT.0,KJ.GE.0)) GO TO 60
6720      IF (KI.NE.KJ) GO TO 70
6730      50 CONTINUE
6740      60 IF(EQV(KI.LT.0,KJ.GE.0))GOTO 90
6750      GO TO 80
6760      70 IF (EQV(KI.LT.KJ,MODE(L).LT.0)) GO TO 90
6770C
6780C RECORDS LINK(I), LINK(J) OUT OF ORDER
6790C
6800      80 II = I-M
6810      LINK(II)=LINK(I)
6820      I=I-M
6830      IF (I.GT.0) GO TO 40
6840C
6850C RECORDS LINK(I), LINK(J) ALREADY IN ORDER
6860C
6870      90 II = I-M
6880      LINK(II)=LJ
6890      100 CONTINUE
6900C
6910C END OF SORT PASS
6920C

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```

6930      IF (M.GT.15) M=M/2
6940      M=M/2
6950      IF (M.NE.0) GO TO 30
6960C
6970C  END OF SORT, TEST WHICH OPTION
6980C
6990      IF (IF.EQ.0) RETURN
7000C
7010C  REARRANGE RECORDS IN A ACCORDING TO LINK
7020C
7030      DO 150 I=1,NROW
7040      IF (LINK(I).EQ.I) GO TO 150
7050      DO 110 K=1,NCOL
7060      TEMP(K)=A(I,K)
7070  110 CONTINUE
7080      IF (ICIND.EQ.0) GO TO 117
7090      DO 115 I115=1,ICCOL
7100      CTEMP(I115)=CHAT(I,I115)
7110  115 CONTINUE
7120  117 CONTINUE
7130      J=I
7140C
7150C  BEGIN CYCLE
7160C
7170  120 LJ=LINK(J)
7180      DO 130 K=1,NCOL
7190  130 A(J,K)=A(LJ,K)
7200      IF (ICIND.EQ.0) GO TO 137
7210      DO 135 I135=1,ICCOL
7220      CHAT(J,I135)=CHAT(LJ,I135)
7230  135 CONTINUE
7240  137 CONTINUE
7250      LINK(J)=J
7260      J=LJ
7270      IF (LINK(J).NE.I) GO TO 120
7280C
7290C  END OF CYCLE
7300C
7310      DO 140 K=1,NCOL
7320  140 A(J,K)=TEMP(K)
7330      IF (ICIND.EQ.0) GO TO 147
7340      DO 145 I145=1,ICCOL
7350      CHAT(J,I145)=CTEMP(I145)
7360  145 CONTINUE
7370  147 CONTINUE
7380      LINK(J)=J
7390  150 CONTINUE
7400      RETURN
7410      END

```

APPENDIX E
SAMPLE DATA BASE

DATA FILE FORMAT

Level	Source	Variables
ATE SYSTEM	GOVERNMENT	LN* TOH POH PIUP M OS NSYS UEBASE TARGAVAL
	GOVERNMENT	LN OSTCON OSTOS IMC RMC PSC PSO TRB TRD
	GOVERNMENT	LN TD SA MRO MRF SR TR PMB PMD CARF
SUBSYSTEM	CONTRACTOR	LN XYS SYSNOUN
	CONTRACTOR	LN BCA DCA DPA N
	CONTRACTOR	LN H JJ SMH SMI TCB TCD TE
	CONTRACTOR	LN BLR DLR DMR DAA DRCTC DRCTO
	CONTRACTOR	LN SCI SCMH CIVLR CASYS
TEST REPLACEABLE UNIT	CONTRACTOR	LN XTRU TRUNOUN
	CONTRACTOR	LN QPA UC MTBF RIP DCOND DMC
	CONTRACTOR	LN PAMH IMH RMH DBCMH DMH W PP K
	CONTRACTOR	LN TRUCI TRUCMH CILR CIILR FICR CI CII CIV FIICR FIVCR CATRU
SUPPORT EQUIPMENT	CONTRACTOR	LN XSE CAD COD DUR DOWN

*LN is the data line number in the data file.

1000 40000 20000 10 9 .3 3 2 .9
1010 .4 .5 57 127 .72 1.5 .14 .15
1020 200 8.4 .08 .24 .25 .16 1728 1728 .25
1030 FAAA00 COMPUTER TEST STA GSM231
1040 10000 20000 5000 35
1050 100 200 5 120 10000 10000 6000
1060 16 30 8 168 1.4 1.9
1070 90 20 16 1
1080 FAAA00 PANEL POWER DIST
1090 7 1800 800 .6 .05 .1
1100 1 1 2 2 2 10 0 .5 1
1110 0 0 0 0 0 0 0 0 0 0
1120 TESTSET1 5000 .1 .2 .1
1130 FAAB00 MAINTENANCE TEST PACK
1140 1 2000 1000 .9 .02 .1
1150 1 1 2 2 2 5 0 .5 0
1160 120 20 30 16 20 0 1 0 8 0 1
1170 FAAC00 PANEL LRU
1180 2 800 700 .2 .1 .2
1190 1 1 2 2 2 2 0 .5 1
1200 90 10 30 16 5 0 1 0 5 0 1
1210 TESTSET1 5000 .1 .2 .1
1220 FAAE00 CARD FILE AUX B
1230 12 1000 500 .05 .1 .2
1240 1 1 2 2 2 2 0 .5 1
1250 90 10 30 16 5 0 1 0 5 0 1
1260 TESTSET1 5000 .1 .2 .1
1270 FAAG00 CONVERTER ASSY TRANS
1280 16 1200 600 .2 .1 .1
1290 1 1 2 2 2 2 0 .5 1
1300 180 10 30 16 10 0 1 0 5 0 1
1310 TESTSET2 10000 .1 .2 .1
1320 FAAJ00 CARDFILE AUX A
1330 2 2500 800 .2 .1 .1
1340 1 1 2 2 2 2 0 .5 1
1350 90 10 30 16 5 0 1 0 5 0 1
1360 TESTSET1 5000 .1 .2 .1
1370 FAAL00 GENERATOR SIGNAL WAVE
1380 17 900 550 .2 .1 .1
1390 1 1 2 2 2 2 0 .5 1
1400 90 10 30 16 5 0 1 0 5 0 1
1410 TESTSET1 5000 .1 .2 .1
1420 FAAP00 CONVERTER SIGNAL
1430 10 900 650 .1 .05 .1
1440 1 1 2 2 2 2 0 .5 1

1450 90 10 30 16 5 0 1 0 5 0 1
1460 TESTSET1 5000 .1 .2 .1
1470 FAARO GENERATOR PRESSURE
1480 14 500 400 .1 .05 .1
1490 1 1 2 2 2 2 0 .5 1
1500 0 0 0 0 0 0 0 0 0 0 0
1510 TESTSET3 10000 .1 .2 .1
1520 FAAUO PRESSURE SUPPLY
1530 5 200 500 .1 .05 .1
1540 1 1 2 2 2 2 0 .5 1
1550 0 0 0 0 0 0 0 0 0 0 0
1560 TESTSET3 10000 .1 .2 .1
1570 FAAWO IMPEDENCE UNIT
1580 17 800 400 .1 .05 .1
1590 1 1 2 2 2 2 0 .5 1
1600 90 10 30 16 5 0 1 0 5 0 1
1610 TESTSET1 5000 .1 .2 .1
1620 FAAYO PANEL AUX DIGITAL
1630 17 600 550 .1 .05 .1
1640 1 1 2 2 2 2 0 .5 1
1650 120 10 30 16 5 0 1 0 5 0 1
1660 TESTSET1 5000 .1 .2 .1
1670 FAA20 POWER SUPPLY PRE
1680 6 400 850 .1 .05 .1
1690 1 1 2 2 2 2 0 .5 1
1700 180 10 30 16 5 0 1 0 5 0 1
1710 TESTSET2 10000 .1 .2 .1
1720 FAA50 POWER SUPPLY ASSY
1730 6 350 900 .1 .05 .1
1740 1 1 2 2 2 2 0 .5 1
1750 0 0 0 0 0 0 0 0 0 0 0
1760 TESTSET2 10000 .1 .2 .1
1770 FAA70 SYNCHRO UNIT
1780 8 700 600 .1 .05 .1
1790 1 1 2 2 2 2 0 .5 0
1800 120 10 30 16 5 0 1 0 5 0 1
1810 FABO PANEL CONTROL
1820 41 1000 1100 .1 .05 1
1830 1 1 2 2 2 2 0 .5 1
1840 180 10 30 16 5 0 1 0 5 0 1
1850 TESTSET1 5000 .1 .2 .1
1860 FABJO PRINTER
1870 9 500 600 .1 .05 1
1880 1 1 2 2 2 2 0 .5 1

1890 120 10 30 16 5 0 1 0 5 0 1
1900 TESTSET1 5000 .1 .2 .1
1910 FABKO MULTIMETER DIGITAL
1920 14 800 1000 .1 .05 1
1930 1 1 2 2 2 2 0 .5 1
1940 180 10 30 16 5 0 1 0 5 0 1
1950 TESTSET1 5000 .1 .2 .1
1960 FABMO OSCILLOSCOPE
1970 13 400 1000 .1 .05 .1
1980 1 1 2 2 2 2 0 .5 0
1990 180 10 30 16 5 0 1 0 5 0 1
2000 FABRO READER PUNCH TAPE
2010 10 800 400 .1 .05 .1
2020 1 1 2 2 2 2 0 .5 1
2030 0 0 0 0 0 0 0 0 0 0 0
2040 TESTSET1 5000 .1 .2 .1
2050 FABTO ANALYZER SAMPLING
2060 11 1200 500 .1 .05 .1
2070 1 1 2 2 2 2 0 .5 1
2080 180 10 30 16 5 0 1 0 5 0 1
2090 TESTSET1 5000 .1 .2 .1
2100 FABZO COUPLER DATA
2110 12 300 100 .1 .05 .1
2120 1 1 2 2 2 2 0 .5 1
2130 120 10 30 16 5 0 1 0 5 0 1
2140 TESTSET1 5000 .1 .2 .1
2150 FAB30 POWR SUPPLY ASSY
2160 9 800 1100 .1 .05 .1
2170 1 1 2 2 2 2 0 .3 1
2180 0 0 0 0 0 0 0 0 0 0 0
2190 TESTSET1 5000 .1 .2 .1
2200 FAB50 TRANSFORMER POWER
2210 5 300 1100 .1 .05 .1
2220 1 1 2 2 2 2 0 .5 1
2230 0 0 0 0 0 0 0 0 0 0 0
2240 TESTSET2 10000 .1 .2 .1
2250 FAB70 COUNTER DIGITAL
2260 14 500 900 .1 .05 .1
2270 1 1 2 2 2 2 0 .5 1
2280 180 10 30 16 5 0 1 0 5 0 1
2290 TESTSET1 5000 .1 .05 .1
2300 FACDO SWITCHING COMPLEX
2310 60 500 1500 .1 .05 .1
2320 1 1 2 2 2 2 0 .5 1

2330 180 10 30 16 5 0 1 0 5 0 1
 2340 TESTSET4 20000 .1 .05 .1
 2350 FACK0 ADAPTER
 2360 1 1500 1200 .1 .05 .1
 2370 1 1 2 2 2 2 0 .5 1
 2380 0 0 0 0 0 0 0 0 0 0 0
 2390 TESTSET4 20000 .1 .05 .1
 2400 FACPO SCOSBY TABLE
 2410 3 2000 1500 .1 .05 .1
 2420 1 1 2 2 2 2 0 .5 0
 2430 0 0 0 0 0 0 0 0 0 0 0
 2440 FACRO RATE OF TURN SYSTEM
 2450 1 1600 1200 .1 .05 .1
 2460 1 1 2 2 2 2 0 .5 1
 2470 120 10 30 16 5 0 1 0 5 0 1
 2480 TESTSET1 5000 .1 .05 .1
 2490 FAC40 TIME BASE DUAL
 2500 1 600 1500 .1 .05 .1
 2510 1 1 2 2 2 2 0 .5 1
 2520 120 10 30 16 5 0 1 0 5 0 1
 2530 TESTSET1 5000 .1 .05 .1
 2540 FACT0 AMP DUAL TRACE
 2550 4 1000 1200 .1 .05 .1
 2560 1 1 2 2 2 2 0 .5 1
 2570 120 10 30 16 5 0 1 0 5 0 1
 2580 TESTSET1 5000 .1 .05 .1
 2590 FADBO EXT CONTROL PANEL
 2600 9 3000 800 .1 .05 .1
 2610 1 1 2 2 2 2 0 .5 1
 2620 120 10 30 16 5 0 1 0 5 0 1
 2630 TESTSET1 5000 .1 .05 .1
 2640 FADDO SAMPLING HEAD
 2650 3 400 1200 .1 .05 .1
 2660 1 1 2 2 2 2 0 .5 1
 2670 120 10 30 16 5 0 1 0 5 0 1
 2680 TESTSET1 5000 .1 .05 .1
 2690 FADKO BATT TEST SET
 2700 3 400 2000 .1 .05 .1
 2710 1 1 2 2 2 2 0 .5 0
 2720 0 0 0 0 0 0 0 0 0 0 0
 2730 FAEAO MASS STORAGE UNIT
 2740 1 2000 500 .1 .05 .1
 2750 1 1 2 2 2 2 0 .5 1
 2760 0 0 0 0 0 0 0 0 0 0 0

2770 TESTSET1 5000 .1 .05 .1
 2780 FAM00 DISPLAYS TEST STATION
 2790 10000 20000 5000 2
 2800 100 200 5 120 10000 10000 6000
 2810 16 30 8 168 1.4 1.9
 2820 9C 20 16 1
 2830 FAMAO PANEL POWER DISTRIB
 2840 7 1800 800 .6 .05 .1
 2850 1 1 2 2 2 2 0 .5 1
 2860 0 0 0 0 0 0 0 0 0 0
 2870 TESTSET1 5000 .1 .2 .1
 2880 FAMCO GENERATOR PULSE
 2890 1 2000 1000 .9 .02 .1
 2900 1 1 2 2 2 2 0 .5 0
 2910 1 20 20 30 16 20 0 1 0 8 0 1
 2920 FAY00 MICROWAVE TEST STATION
 2930 5000 20000 5000 1
 2940 100 200 5 120 10000 6000 6000
 2950 16 30 6 168 1.4 1.9
 2960 120 20 16 1
 2970 FAYBO MAINT TEST PACK.
 2980 1 2000 1500 .6 .05 .1
 2990 1 1 2 2 2 2 0 .5 1
 3000 1 20 20 30 16 30 0 1 0 8 0 1
 3010 TESTSET4 20000 .1 .05 .1

APPENDIX F
SAMPLE OUTPUT

RUN OF 08/23/79 -- 1312 HOURS

TOTAL LSC = \$ 15.93 MILLION.

DO YOU WANT AN EXPLANATION OF YOUR AVAILABLE OPTIONS?
-YES

OPTION 1 - TOTAL LSC BROKEN OUT BY EQUATION
OPTION 2 - ALL SYSTEMS RANKED ON COST
OPTION 3 - COST BREAKOUT BY EQUATION FOR A PARTICULAR SYSTEM
OPTION 4 - COST RANKING OF TRUS FOR A PARTICULAR SYSTEM
OPTION 5 - COST BREAKOUT BY EQUATION FOR A PARTICULAR TRU
OPTION 6 - DETAILED SUPPORT EQUIPMENT ANALYSIS
OPTION 7 - DETAILED SPARES ANALYSIS
OPTION 8 - MAINTENANCE GENERATIONS ANALYSIS
OPTION 9 - TRU WORK UNIT CODE/NOON CROSS-REFERENCE
OPTION 10 - STOP PROGRAM

WHICH OPTION?

-1

EQUATION	#1	#2	#3	#4	#5
	4681700.	328285.	1415602.	79154.	7700000.
EQUATION	#6	#7	#8		
	69771.	219805.	1439641.		

WHICH OPTION?

-2

SYSTEM	COST(IN MILLIONS)	FRACTION OF TOTAL LSC
FAA00	9.03	0.57
FAM00	0.46	0.03
PAY00	0.26	0.02

WHICH OPTION?

-3

SYSTEM IDENTIFICATION?
-FAA00

EQUATION	#1	#2	#3	#4	#5
	4542100.	271439.	1404636.	72905.	1130000.
EQUATION	#6	#7	#8		
	52947.	98170.	1438506.		

WHICH OPTION?

3
SYSTEM IDENTIFICATION?
-FAM00

EQUATION	#1	#2	#3	#4	#5
	115600.	29932.	10175.	4166.	230000.
EQUATION	#6	#7	#8		
	8618.	60966.	549.		

WHICH OPTION?
-3
SYSTEM IDENTIFICATION?
-FAY00

EQUATION	#1	#2	#3	#4	#5
	24000.	26894.	791.	2083.	140000.
EQUATION	#6	#7	#8		
	8206.	60668.	487.		

WHICH OPTION?
-4
SYSTEM IDENTIFICATION?
-FAY00
HOW MANY TRUS TO BE INCLUDED IN RANKING?
-1

	TRU	COST	FRACTION OF SYSTEM COST
1	FAY80	27150.	0.10

CONTRIBUTION OF TOP 1TRUS- 10 PER CENT OF TOTAL SYSTEM COST.
SYSTEM COST = \$ 0.26 MILLION.

WHICH OPTION?
-4
SYSTEM IDENTIFICATION?
-FAM00
HOW MANY TRUS TO BE INCLUDED IN RANKING?
-2

	TRU	COST	FRACTION OF SYSTEM COST
1	FAMAO	109256.	0.24
2	FAMCO	24730.	0.05

CONTRIBUTION OF TOP 2TRUS- 29 PER CENT OF TOTAL SYSTEM COST.
SYSTEM COST = \$ 0.46 MILLION.

WHICH OPTION?

4
 SYSTEM IDENTIFICATION?
 -FAA00
 HOW MANY TRUS TO BE INCLUDED IN RANKING?
 -35

	TRU	COST	FRACTION OF SYSTEM COST
1	FABO	872462.	0.10
2	FABZO	623834.	0.07
3	FAAWO	553162.	0.06
4	FACDO	501133.	0.06
5	FADBO	447935.	0.05
6	FAALO	447163.	0.05
7	FAAEO	432825.	0.05
8	FAAGO	412979.	0.05
9	FABTO	374481.	0.04
10	FAAYO	348833.	0.04
11	FABKO	294701.	0.03
12	FABRO	264964.	0.03
13	FAAPO	264564.	0.03
14	FAARO	251877.	0.03
15	FABJO	219627.	0.02
16	FAA7O	178966.	0.02
17	FAB7O	170591.	0.02
18	FABMO	137139.	0.02
19	FAAAO	109897.	0.01
20	FAAJO	107316.	0.01
21	FAB3O	99230.	0.01
22	FACTO	81134.	0.01
23	FAA2O	73898.	0.01
24	FACPO	70586.	0.01
25	FAEAO	70586.	0.01
26	FAACO	60149.	0.01
27	FAA5O	45758.	0.01
28	FAAUO	45396.	0.01
29	FADDO	40636.	0.00
30	FACKO	40439.	0.00
31	FAABO	35444.	0.00
32	FACRO	34001.	0.00
33	FAB5O	30180.	0.00
34	FAC4O	22779.	0.00
35	FADKO	19840.	0.00

CONTRIBUTION OF TOP 35TRUS- 86 PER CENT OF TOTAL SYSTEM COST.
 SYSTEM COST - \$ 9.03 MILLION.

WHICH OPTION?

5
 TRU IDENTIFICATION?
 -FASO

EQUATION	#1	#2	#3	#4
	361000.	15373.	139138.	2083.
EQUATION	#5	#6	#7	#8
	0.	2838.	2380.	149650.

WHICH OPTION?
 -6

COL 1 - SE IDENTIFICATION
 COL 2 - FRACTIONAL SE RQMT-BASE (COMPUTED)
 COL 3 - TOTAL SE RQMT-BASE (INTEGERIZED)
 COL 4 - FRACTIONAL SE RQMT-DEPOT (COMPUTED)
 COL 5 - TOTAL SE RQMT-DEPOT (INTEGERIZED)

	1	2	3	4	5
TESTSET1		0.	0.	277.89	278.
TESTSET2		0.	0.	21.34	22.
TESTSET3		0.	0.	23.21	24.
TESTSET4		0.	0.	84.87	85.

WHICH OPTION?
 -

7

TRUS						
WUC	DMDMEAN	XBO	AV	STK	DPIPE	TOTCOND
FAAAO	0.74	0.01	0.9959	3.	23.	2.
FAABO	0.02	0.00	0.9999	1.	1.	1.
FAACO	0.49	0.00	0.9991	3.	15.	3.
FAAE0	4.84	0.01	0.9967	11.	142.	21.
FAAGO	4.53	0.01	0.9946	10.	133.	19.
FAAJ0	0.42	0.01	0.9948	2.	13.	2.
FAALO	5.25	0.00	0.9977	12.	154.	22.
FAAPO	2.94	0.00	0.9977	8.	91.	7.
FAARO	6.69	0.00	0.9988	15.	207.	14.
FAAU0	1.91	0.00	0.9995	7.	59.	4.
FAAU0	8.12	0.01	0.9963	16.	251.	17.
FAAY0	5.91	0.01	0.9975	13.	183.	13.
FAA20	1.35	0.00	0.9984	5.	42.	3.
FAA30	1.27	0.00	0.9988	5.	40.	3.
FAA70	2.55	0.01	0.9968	7.	79.	6.
FAB0	7.12	0.01	0.9944	14.	220.	15.
FABJ0	2.87	0.00	0.9981	8.	89.	6.
FABK0	2.68	0.00	0.9988	8.	83.	6.
FABM0	2.48	0.00	0.9993	8.	77.	6.
FABRO	4.78	0.01	0.9971	11.	148.	10.
FABT0	4.20	0.01	0.9970	10.	130.	9.
FABZ0	22.93	0.00	0.9985	38.	707.	48.
FAB30	1.56	0.01	0.9966	5.	49.	4.
FAB50	0.87	0.00	0.9988	4.	27.	2.
FAB70	2.97	0.00	0.9975	8.	92.	7.
FACD0	7.64	0.00	0.9980	16.	236.	16.
FACK0	0.16	0.00	0.9997	2.	5.	1.
FACP0	0.38	0.01	0.9961	2.	12.	1.
FACR0	0.16	0.01	0.9940	1.	5.	1.
FAC40	0.13	0.00	0.9998	2.	4.	1.
FACT0	0.64	0.00	0.9976	3.	20.	2.
FAD80	2.15	0.03	0.9844	5.	67.	5.
FADDO	0.48	0.00	0.9992	3.	15.	1.
FADK0	0.29	0.00	0.9999	3.	9.	1.
FAEA0	0.38	0.01	0.9961	2.	12.	1.
FAMA0	0.74	0.01	0.9959	3.	23.	2.
FAMC0	0.02	0.00	0.9999	1.	1.	1.
FAT30	0.06	0.00	0.9992	1.	2.	1.

SYSTEM AVAILABILITY 0.903

WHICH OPTION?

8

WUC	PEAK GENS	PEAK OFF-EQUIP GENS	TOTAL GENS	TOTAL OFF-EQUIP GENS
FAAAO	38.89	15.56	77.78	31.11
FAABO	4.44	0.44	8.89	0.89
FAACO	12.70	10.16	25.40	20.32
FAAKO	106.67	101.33	213.33	202.67
FAAGO	118.52	94.81	237.04	189.63
FAAJ0	11.11	8.89	22.22	17.78
FAALO	137.37	109.90	274.75	219.80
FAAPO	68.38	61.54	136.75	123.08
FAARO	155.56	140.00	311.11	280.00
FAAU0	44.44	40.00	88.89	80.00
FAAW0	188.89	170.00	377.78	340.00
FAAY0	137.37	123.64	274.75	247.27
FAAZ0	31.37	28.24	62.75	56.47
FAA50	29.63	26.67	59.26	53.33
FAA70	59.26	53.33	118.52	106.67
FAB0	165.66	149.09	331.31	298.18
FABJ0	66.67	60.00	133.33	120.00
FABK0	62.22	56.00	124.44	112.00
FABH0	57.78	52.00	115.56	104.00
FABRO	111.11	100.00	222.22	200.00
FABTO	97.78	88.00	195.56	176.00
FABZO	533.33	480.00	1066.67	960.00
FAB30	36.36	32.73	72.73	65.45
FAB50	20.20	18.18	40.40	36.36
FAB70	69.14	62.22	138.27	124.44
FACD0	177.78	160.00	355.56	320.00
FACK0	3.70	3.33	7.41	6.67
FACPO	8.89	8.00	17.78	16.00
FACRO	3.70	3.33	7.41	6.67
FAC40	2.96	2.67	5.93	5.33
FACT0	14.81	13.33	29.63	26.67
FADBO	50.00	45.00	100.00	90.00
FADDO	11.11	10.00	22.22	20.00
FADK0	6.67	6.00	13.33	12.00
FAEAO	8.89	8.00	17.78	16.00
FAMAO	38.89	15.56	77.78	31.11
FAMCO	4.44	0.44	8.89	0.89
FAYBO	2.96	1.19	5.93	2.37

WHICH OPTION?

9

WUC	NOUN
FAAAO	PANEL
FAABO	MAINTENANCE
FAACO	PANEL
FAAEO	CARD
FAAGO	CONVERTER
FAAJO	CARDFILE
FAALO	GENERATOR
FAAP0	CONVERTER
FAARO	GENERATOR
FAAU0	PRESSURE
FAAWO	IMPEDENCE
FAAYO	PANEL
FAAZO	POWER
FAAJO	POWER
FAA7O	SYNCHRO
FABO	PANEL
FABJO	PRINTER
FABKO	MULTIMETER
FABMO	OSCILLOSCOPE
FABRO	READER
FABTO	ANALYZER
FABZO	COUPLER
FABJO	POWR
FABJO	TRANSFORMER
FAB7O	COUNTER
FACDO	SWITCHING
FACKO	ADAPTER
FACPO	SCOSBY
FACRO	RATE
FAC4O	TIME
FACTO	AMP
FADBO	EXT
FADDO	SAMPLING
FADKO	BATT
FAEAO	MASS
FANAO	PANEL
FANCO	GENERATOR
FATBO	MAINT

WHICH OPTION?
-10

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